
SECTION 5

SURFACE SAMPLE ANALYSIS

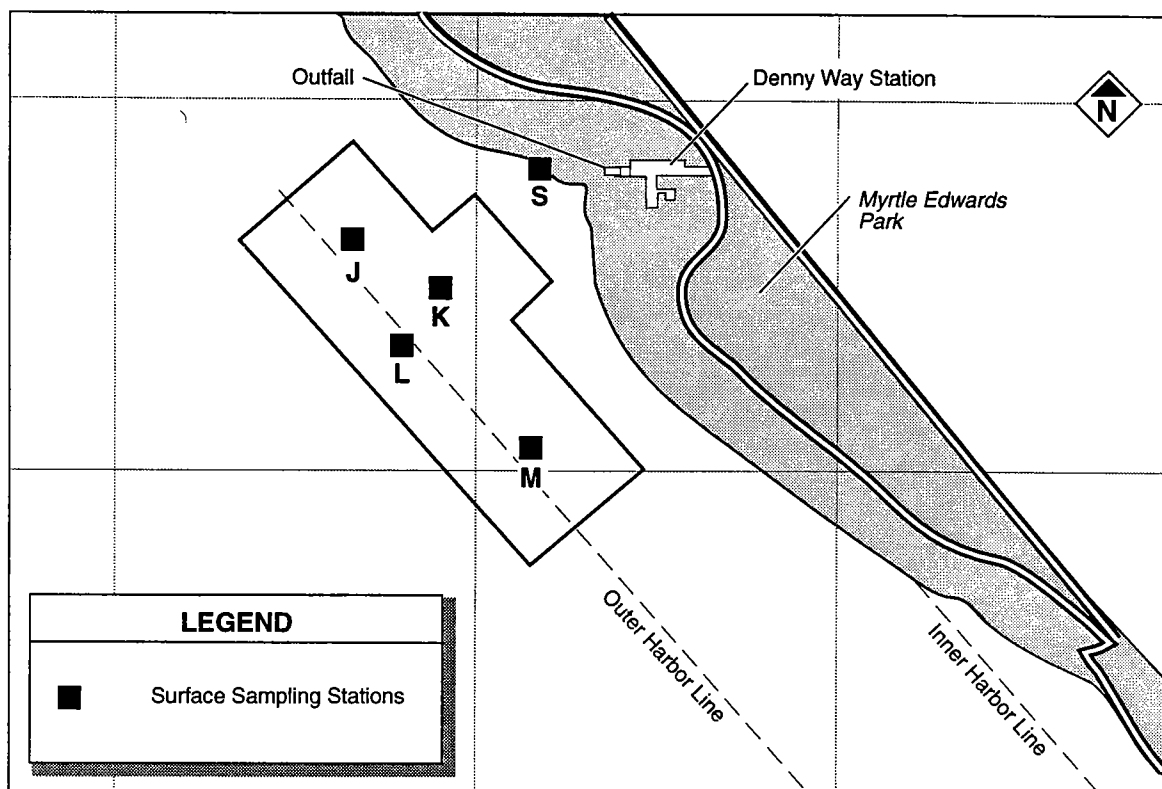
This section meets the fourth objective in the monitoring plan, which is to identify whether chemicals accumulate in the surface of the cap, indicating a need for any additional specific toxicant source control work upstream in the Denny Way collection system.

Surface sediment samples were collected during 1990, 1991, and 1992 at five stations to evaluate cap surface concentrations (see Map 5-1). The samples were analyzed for metals, organic compounds, and conventionals. Sampling in the first year established the baseline distribution of chemicals in the study area. Subsequent years were compared to the baseline data to demonstrate trends in chemical concentrations on the surface of the sediment cap.

METHODS

Four subtidal stations were arranged on the sand cap in a pattern like a narrow diamond with the long axis parallel to shore. Station K was the on-cap station closest to the outfall. Stations J and L were farther away but approximately equidistant from the outfall, and M was farther away still. A fifth surface station (S) was located inshore of the cap in a sandy, intertidal area near the outfall. Inshore of Station S, closer to the outfall, were gravel, boulders and rip-rap. All on-cap surface grab stations were located away from the core stations so as not to be affected by contamination released during coring; however, three of the surface stations were used to represent surface conditions at the core locations. As illustrated in the vertical profiles of representative pollutants (see Section 4, Figures 4-3 to 4-15), grab K was matched to core O, grab J to core N and grab M to core P.

Samples from the four subtidal stations were collected with a 0.1-square-meter Van Veen grab sampler operated from Metro's research vessel, *RV Liberty*. Three individual grab samples were taken at each station. Field personnel used a stainless steel "cookie cutter" and spatula to collect a subsample from the top two centimeters of each grab. The subsamples were composited in a 4-liter beaker that had been cleaned in a muffle furnace at 500°C, as were the cookie cutter and spatula. A teflon stir bar was used to homogenize the sample before containers for the various tests were filled.

Methods

Map 5-1. Surface Sampling Stations

Intertidal samples were collected at low tide by pushing a 2-inch-diameter, 12-inch-long stainless steel tube into the sand until it was 4 to 7 inches deep. Then the tube was rotated and a spatula was slid underneath to prevent the sample from falling out. The tube and spatula had been cleaned in a muffle-furnace prior to sampling. A complete description of laboratory methods is provided in Appendix E.

Like the core data, all grab data were normalized to dry weight for comparison between stations and years and selected data were normalized for total organic carbon content for comparison to the Washington State Sediment Management Standards (SMS). Semivolatile and volatile organics, PCBs and pesticides were reported as parts per billion dry weight and metals were reported as parts per million dry weight. The selected organic compounds normalized for total organic carbon (percent TOC) content were reported as mg/kg organic carbon.

The cap surface baseline data was collected in early April 1990, within days of the completion of sampling, while the intertidal sample was collected in late May. In 1991, the four subtidal stations were sampled in late May and the intertidal station was sampled in mid-June. Two subtidal sampling events were conducted in 1992. The regular monitoring occurred in late May. Two additional grab samples were taken at Stations J and K in August to detect whether contaminated nearshore sediments, which were scoured during a substantial discharge from the Denny Way CSO at approximately a zero tide, had settled onto the cap. The 1992 intertidal sample was collected in early July.

THREE-YEAR SUMMARY

Chemical concentrations found on the cap in the 1990 baseline study showed that the cap surface was very much like the pre-dredge Duwamish River analysis and the within-cap core samples. Three PAHs and eleven metals were found in all four cap surface samples. Two additional PAHs and two other organic compounds were found in at least two cap samples. There was little if any spatial variation; the southernmost site (M) had the fewest detected chemicals and the lowest concentrations, but the other three sites were nearly identical. All concentrations were well below the SMS sediment quality standards (SQS).

Baseline study of the intertidal Station S, which is inshore of the cap and near the Denny Way CSO, showed that concentrations were similar to that of the below-cap sediments. Of the 20 semivolatile organic compounds found below the cap, 16 were detected at S. Most metals concentrations at S were within the same range or lower, although concentrations of three metals were higher at S than in the below-cap samples.

The second study in 1991 detected more compounds at all of the on-cap stations and higher concentrations of previously detected compounds. At least six PAHs were detected at all stations compared to three PAHs in 1990. The average concentration of previously detected PAHs increased two- to eight-fold. Average metals concentrations increased at slower rates than the PAHs. Silver was detected at the three northern sites. Trace amounts of one PCB appeared at two of the four on-cap sites. Pesticides and volatile organics were undetected. The intertidal uncapped site, Station S, was largely unchanged from 1990.

The baseline study showed that the cap surface was reasonably homogeneous, while in 1991 distinct spatial differences developed in the distribution

Three-Year Summary

of PAHs. The on-cap station closest to the outfall and shore (K) showed the largest increases. Stations seaward (L) and north (J) of K were subject to lower but still notable increases. The station to the south (M) was the least affected.

Spatial differences in the distribution of metals were not as apparent. All four stations showed increases. In general, the three northern stations had similar metals composition, with concentrations only slightly higher than those found at the southernmost station.

In 1992, the second year after cap placement, concentrations and the number of parameters detected continued to rise. A minimum of 12 PAHs were detected at each station, up from six the year before. Three more metals—cadmium, antimony and thallium—were detected for the first time at all four stations. At Station M, PAH concentrations rose more than they had between 1990 and 1991. Rates of PAH increases at the other three stations were lower than the previous year. Lead, mercury and silver were the only metals to increase noticeably at K.

In 1992 the spatial differentiation between stations was not as distinct as in 1991. Station K, closest to the discharge and closest to shore, continued to have the highest concentrations and the most compounds detected, but spatial differences between the other three stations became less pronounced. The most substantial increases occurred at M, which is farthest south; its chemical composition became more like J and L. L showed the least amount of change. It is unclear why much lower chemical concentrations were found at the intertidal Station S, but this occurrence brought many of its values to within the same range as those found on the cap.

A storm discharge that scoured nearshore and intertidal contaminated sediments did not appear to cause any measurable increases in chemical concentrations on the cap. Concentrations were unchanged or lower at one of the two stations where post-storm samples were collected. The other station did not appear to be significantly affected.

Of the HPAHs detected on the cap, the highest concentrations were mostly less than 10 percent of the SQS, while two were less than 15 percent. Total HPAHs were also less than 10 percent of the SQS. All LPAHs that were detected on the cap were less than 10 percent of the SQS, showing that HPAHs are increasing faster than LPAHs. Total PCBs increased between the studies but were less than 50 percent of the SQS.

Most metals were less than 10 percent of the SQS, while zinc was less than 20 percent and mercury for all samples except one was less than 50 percent of the SQS. The one exception was Station M, the farthest away from the Denny Way CSO, which had a surprisingly high mercury value that exceeded the cleanup screening levels (CSL). Replicate sampling is needed in 1994 to verify the high level.

One phthalate showed variable concentrations over the three studies, with the highest concentration in 1991. In 1992, one phthalate was less than 80 percent of the SQS while another was about 20 percent.

Evaluation and comparison of detection limits to the sediment standards was difficult in the first two studies because of the low organic carbon content of the samples. In the 1992 study, the organic carbon content had increased and in turn this reduced the number of detection limits that exceeded of the sediment standards.

Video camera surveys conducted in 1990, 1991, and 1992 (see Section 6) showed a layer of fine silt mixed with organic debris and plant growth that appeared to increase in thickness each year. The same layer was also noted in the sediment-profile camera survey (see Appendix D). However, both the sediment-profile images and the video camera images showed that in some areas of the cap there was exposed sand with no organic layer. These clear areas appear to be the result of some physical force such as a diver or rope brushing the fine material away. The contamination found on the cap in 1991 is presumably sorbed to the fine material. The two most likely sources of the contaminated fine sediments were solids discharged from the outfall or contaminated nearshore sediments redistributed onto the cap. To help clarify the source, stormwater samples have been analyzed and will be interpreted, and additional sediment sampling is being planned to investigate the nearshore area.

Among the many potential sources of fine contaminated particles, two are expected to be the most likely contributors to the Denny Way cap area; the contaminated nearshore sediments, and particles in the Denny Way CSO stormwater. Stormwater samples from the Denny Way CSO have been analyzed for priority pollutants in the whole and solids fractions, but the data has not been interpreted yet. Additional intertidal and nearshore sites could be considered for sampling in 1994.

1990 Results

1990 RESULTS

For the first year, the monitoring plan (Appendix A) focused on identifying chemicals on the cap surface, comparing surface results to the pre-dredge and core results, and identifying spatial differences. As described above, grab stations have been linked to core stations in the vertical profile plots to facilitate comparison. Because the 1990 sampling was within one week of the completion of the actual capping process, the results could be used as baseline data for within the cap as well as on the cap surface because there was little potential for recontamination.

Summary

Three PAHs and eleven metals were found in all four cap surface samples collected in 1990. Three additional PAHs and two additional organic compounds were found in at least two cap samples. The composition of semivolatile organic compounds and metals found on the cap surface was very much like that found in the pre-dredge analysis and throughout the cap in 1990. There was little if any spatial variation; the southernmost site (M) had a few less detected organic compounds and slightly lower concentrations while the other three were essentially identical. All concentrations were well below the SQS.

Specifics

The LPAH phenanthrene and the HPAHs fluoranthene, and pyrene were detected in all four cap surface samples (see Tables 5-1 and 5-2). Bis(2-ethylhexyl)phthalate and benzoic acid were detected at the three northernmost stations. Eleven metals were detected at all four grab stations; aluminum, arsenic, beryllium, chromium, copper, iron, lead, manganese, mercury, nickel, and zinc. The other metals monitored for (antimony, cadmium, selenium, silver, thallium) were undetected at all cap stations. No pesticides, PCBs, or volatile organics were detected at any of the subtidal stations.

All PAH concentrations were below 50 ppb-dry with most compounds undetected at half that concentration. Bis(2-ethylhexyl)phthalate and benzoic acid had maximum concentrations only as high as 140 ppb-dry in one sample,

TABLE 5-1. Stations J and K: Organic Compounds and Metals

Station/Locator	J LTBC20				J LTBC20				J LTBC20			
Date Sampled	Apr 03, 90				May 28, 91				May 26, 92			
Sample Number	9000327				9101185				9201091			
% Solids:	69				60				68			
% TOC	1.2				0.81				3.2			
BNA Organics (µg/kg dry)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs												
Naphthalene		<MDL	10	36		<MDL	50	83		<MDL	40	74
Acenaphthylene		<MDL	6	12		<MDL	20	28		<MDL	10	25
Acenaphthene		<MDL	4	9.7		<MDL	10	22		<MDL	10	19
Fluorene		<MDL	6	12		<MDL	20	28	10	<RDL	10	25
Phenanthrene	38		6	12	83		20	28	150		10	25
Anthracene		<MDL	6	12	40		20	28	69		10	25
HPAHs												
Fluoranthene	49		7	14	170		20	33	250		10	29
Pyrene	41		6	12	130		20	28	350		10	25
Benzo(a)anthracene	19		6	12	87		20	28	120		10	25
Chrysene	25		6	12	100		20	28	150		10	25
Benzo(b)fluoranthene		<MDL	10	36	100		50	83	150		40	74
Benzo(k)fluoranthene		<MDL	10	36		<MDL	50	83	79		40	74
Benzo(a)pyrene		<MDL	10	25	73		30	55	100		30	49
Indeno(1,2,3-Cd)Pyrene		<MDL	10	25		<MDL	30	55	94		30	49
Dibenzo(a,h)anthracene		<MDL	10	36		<MDL	50	83		<MDL	40	74
Benzo(g,h,i)perylene		<MDL	10	25		<MDL	30	55	120		30	49
Other												
Benzyl Butyl Phthalate		<MDL	6	12		<MDL	20	28		<MDL	10	25
Bis(2-Ethylhexyl)Phthalate	57		6	12		<MDL,B	20	28	590	B	10	25
Di-N-Butyl Phthalate		<MDL	10	25		<MDL,B	30	55		<MDL,B	30	49
Dibenzofuran		<MDL	10	25		<MDL	30	55		<MDL	30	49
Benzoic Acid	140		40	72		<MDL	80	170		<MDL	70	150
Coprostanol									820		70	150
Carbazole										<MDL	30	49
PCBs												
Aroclor 1248		<MDL	10	25		<MDL	10	28		<MDL	30	49
Aroclor 1254		<MDL	10	25	35		10	28		<MDL	30	49
Aroclor 1260		<MDL	10	25		<MDL	10	28		<MDL	30	49
Volatiles												
Acetone		<MDL	40	72		<MDL	20	33		<MDL	40	74
Metals mg/Kg												
Mercury	0.058				0.083				0.16			
Aluminum	11000	E,B			12000				9900			
Antimony		<MDL,G	1			<MDL,G	5		1.5	G		
Arsenic	5.8	E,G			12				4.4	E		
Barium	39	E,B			37				34	B		
Beryllium	0.29	E			0.33				0.29			
Cadmium		<MDL,E	0.3			<MDL	0.3		0.15	E		
Chromium	14	E,B			17	E			13			
Copper	11	E,B			62	B			18			
Iron	19000	E			22000				16000			
Lead	7.2	E			13				12			
Nickel	13	E			13				12			
Selenium		<MDL, G	1			<MDL	8			<MDL	1	
Silver		<MDL, E	0.4		0.67				0.96			
Thallium		<MDL, E	3			<MDL	30		10			
Zinc	49	E			63	B			51			

In 1990 antimony, arsenic, selenium, and thallium were analyzed using GFAA methods. See Appendix E.

<RDL - Detected below quantification limits

<MDL - Undetected at the method detection limit

B - Blank contamination

G - Low standard reference material recovery

L - High standard reference material recovery

E - Estimate based on high relative percent difference in duplicate, high relative standard deviation in triplicate, or high or low surrogate recoveries

1990 Results

TABLE 5-1 (continued). Stations J and K: Organic Compounds and Metals

Station/Locator	K LTBC34				K LTBC21				K LTBC21				K Replicate			
Date Sampled	Apr 03, 90				May 30, 91				May 26, 92				May 26, 92			
Sample Number	9000328				9101186				9201092				9201093			
% Solids:	72				66				61				64.4			
% TOC	0.97				0.52				2.8				2.7			
BNA Organics (µg/kg dry)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs																
Naphthalene	<MDL	10	35		<MDL	50	76		<MDL	50	82		<MDL	50	78	
Acenaphthylene	<MDL	6	12		<MDL	10	26		<MDL	10	28		<MDL	10	26	
Acenaphthene	<MDL	4	9		<MDL	10	20		10	<RDL	10	21	10	<RDL	10	20
Fluorene	<MDL	6	12	27		10	26	33		10	28	36		10	26	
Phenanthrene	40		6	12	200		10	26	260		10	28	230		10	26
Anthracene	<MDL	6	12		110		10	26	120		10	28	150		10	26
HPAHs																
Fluoranthene	49		7	14	350		20	30	410		20	33	450		20	31
Pyrene	33		6	12	260		10	26	340		10	28	250		10	26
Benzo(a)anthracene	15		6	12	150		10	26	230		10	28	190		10	26
Chrysene	15		6	12	200		10	26	310		10	28	280		10	26
Benzo(b)fluoranthene	<MDL	10	35		150		50	76	280		50	82	260		50	78
Benzo(k)fluoranthene	<MDL	10	35		100		50	76	120		50	82	140		50	78
Benzo(a)pyrene	<MDL	10	24		130		30	50	210		30	54	170		30	51
Indeno(1,2,3-Cd)Pyrene	<MDL	10	24		76		30	50	120		30	54	90		30	51
Dibenzo(a,h)anthracene	<MDL	10	35		<MDL	50	76		<MDL	50	82		<MDL	50	78	
Benzo(g,h,i)perylene	<MDL	10	24		61		30	50	140		30	54	90		30	51
Other																
Benzyl Butyl Phthalate	<MDL	6	12		<MDL	10	26		38		10	28	34		10	26
Bis(2-Ethylhexyl)Phthalate	130		6	12	520	B	10	26	1000	B	10	28	890	B	10	26
Di-N-Butyl Phthalate	<MDL	10	24		<MDL	B	30	50	<MDL	B	30	54	<MDL	B	30	51
Dibenzofuran	<MDL	10	24		<MDL	30	50		<MDL	30	54		<MDL	30	51	
Benzoic Acid	110		40	69	<MDL	80	150		<MDL	80	160		<MDL	80	160	
Coprostanol									1100		80	160	960		80	160
Carbazole									61		30	54	75		30	51
PCBs																
Aroclor 1248	<MDL	10	24		<MDL	10	26		<MDL	30	54		<MDL	30	51	
Aroclor 1254	<MDL	10	24		32		10	26	160		30	54	<MDL	30	51	
Aroclor 1260	<MDL	10	24		<MDL	10	26		<MDL	30	54		<MDL	30	51	
Volatiles																
Acetone	<MDL	40	69		<MDL	20	30		<MDL	50	82		<MDL	50	78	
Metals mg/Kg																
Mercury	0.06				0.11				0.2				0.16			
Aluminum	9000	E,B			11000				11000				11000			
Antimony	<MDL	G	1		<MDL	G	5		1.6	G			1.6	G		
Arsenic	4.2	E,G			11				4.9	E			5.7	E		
Barium	36	E,B			35				36	B			33	B		
Beryllium	0.14	E			0.3				0.33				0.31			
Cadmium	<MDL	E	0.3		<MDL	0.3			0.33	E			0.31	E		
Chromium	13	E,B			15	E			18				16			
Copper	9.9	E,B			18	B			26				20			
Iron	15000	E			20000				16000				17000			
Lead	14	E			15				23				16			
Nickel	9.7	E			12				15				13			
Selenium	<MDL	G	1		<MDL	8			<MDL	2			<MDL	2		
Silver	<MDL	E	0.4		0.76				2				1.3			
Thallium	<MDL	E	3		<MDL	30			9.8				11			
Zinc	47	E			64	B			66				59			

In 1990 antimony, arsenic, selenium, and thallium were analyzed using GFAA methods. See Appendix E.

<RDL - Detected below quantification limits

<MDL - Undetected at the method detection limit

B - Blank contamination

G - Low standard reference material recovery

L - High standard reference material recovery

E - Estimate based on high relative percent difference in duplicate, high relative standard deviation in triplicate, or high or low surrogate recoveries

TABLE 5-1 (continued). Stations J and K: Organics and Metals

Station/Locator:	J2 LTBC20				K2 LTBC21			
Sampled:	Aug 20, 92				Aug 20, 92			
Lab ID:	9201596				9201595			
% Solids:	71				68			
% TOC	1.8				2			
BNA Organics (µg/kg dry)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs								
Naphthalene		<MDL	40	70		<MDL	40	74
Acenaphthylene		<MDL	10	23		<MDL	10	25
Acenaphthene		<MDL	9	18	10	<RDL	10	21
Fluorene		<MDL	10	23	51		10	25
Phenanthrene	63		10	23	250		10	25
Anthracene	35		10	23	190		10	25
HPAHs								
Fluoranthene	150		10	28	460		10	29
Pyrene	99		10	23	350		10	25
Benzo(a)anthracene	62		10	23	210		10	25
Chrysene	96		10	23	290		10	25
Benzo(b)fluoranthene	85		40	70	240		40	74
Benzo(k)fluoranthene		<MDL	40	70	180		40	74
Benzo(a)pyrene	58		20	46	160		30	49
Indeno(1,2,3-Cd)Pyrene	40	<RDL	20	46	100		30	49
Dibenzo(a,h)anthracene		<MDL	40	70	40	<RDL	40	74
Benzo(g,h,i)perylene		<MDL	20	46	72		30	49
Other								
Benzyl Butyl Phthalate	24		10	23	65		10	25
Bis(2-Ethylhexyl)Phthalate	560	B	10	23	1500	B	10	25
Di-N-Butyl Phthalate		<MDL,B	20	46		<MDL,B	30	49
Dibenzofuran		<MDL	20	46		<MDL	30	49
Benzoic Acid		<MDL	70	140		<MDL	70	150
Coprostanol		<MDL	70	140		<MDL	70	150
Carbazole		<MDL	20	46	71		30	49
PCBs								
Aroclor 1248								
Aroclor 1254								
Aroclor 1260								
Volatiles								
Acetone		<MDL	40	70		<MDL	40	74
Metals mg/Kg								
Mercury	0.07	E			0.088	E		
Aluminum	9000				8800			
Antimony		<MDL,G	4			<MDL,G	4	
Arsenic	13				8.8			
Barium	38				37			
Beryllium	0.28				0.29			
Cadmium		<MDL	0.3		0.29			
Chromium	13				13			
Copper	15				19			
Iron	17000				15000			
Lead	11				29			
Nickel	13				12			
Selenium		<MDL	7			<MDL	7	
Silver	1.1				1.3			
Thallium		<MDL	30			<MDL	30	
Zinc	49				59			

In 1990 antimony, arsenic, selenium, and thallium were analyzed using GFAA methods. See Appendix E.

<RDL - Detected below quantification limits

<MDL - Undetected at the method detection limit

B - Blank contamination

G - Low standard reference material recovery

L - High standard reference material recovery

E - Estimate based on high relative percent difference in duplicate, high relative standard deviation in triplicate, or high or low surrogate recoveries

1990 Results

TABLE 5-2. Stations L, M, and S: Organic Compounds and Metals

Station/Locator	L LTBC35				L LTBC22				L LTBC22			
Date Sampled	Apr 03, 90				May 30, 91				May 26, 92			
Sample Number	9000329				9101187				9201094			
% Solids:	71				62				67			
% TOC	0.63				0.78				3.7			
BNA Organics (µg/kg dry)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs												
Naphthalene	<MDL		10	35	<MDL		50	81	<MDL		40	75
Acenaphthylene	<MDL		6	12	<MDL		10	27	<MDL		10	25
Acenaphthene	<MDL		4	9.4	<MDL		10	21	<MDL		10	19
Fluorene	<MDL		6	12	<MDL		10	27	10	<RDL	10	25
Phenanthrene	23		6	12	120		10	27	140		10	25
Anthracene	<MDL		6	12	53		10	27	78		10	25
HPAHs												
Fluoranthene	35		7	14	210		20	32	280		10	30
Pyrene	27		6	12	180		10	27	210		10	25
Benzo(a)anthracene	<MDL		6	12	120		10	27	140		10	25
Chrysene	17		6	12	150		10	27	210		10	25
Benzo(b)fluoranthene	<MDL		10	35	130		50	81	180		40	75
Benzo(k)fluoranthene	<MDL		10	35	98		50	81	110		40	75
Benzo(a)pyrene	<MDL		10	24	100		30	53	140		30	49
Indeno(1,2,3-Cd)Pyrene	<MDL		10	24	60		30	53	85		30	49
Dibenzo(a,h)anthracene	<MDL		10	35	<MDL		50	81	<MDL		40	75
Benzo(g,h,i)perylene	<MDL		10	24	<MDL		30	53	76		30	49
Other												
Benzyl Butyl Phthalate	<MDL		6	12	<MDL		10	27	<MDL		10	25
Bis(2-Ethylhexyl)Phthalate	44		6	12	320	B	10	27	460	B	10	25
Di-N-Butyl Phthalate	<MDL		10	24	<MDL,B		30	53	<MDL,B		30	49
Dibenzofuran	<MDL		10	24	<MDL		30	53	<MDL		30	49
Benzoic Acid	110		40	70	<MDL		80	160	<MDL		70	150
Coprostanol									520		70	150
Carbazole									<MDL		30	49
PCBs												
Aroclor 1248	<MDL		10	24	<MDL		10	27	<MDL		30	49
Aroclor 1254	<MDL		10	24	<MDL		10	27	120		30	49
Aroclor 1260	<MDL		10	24	<MDL		10	27	<MDL		30	49
Volatiles												
Acetone	<MDL		40	70	<MDL		20	32	<MDL		40	75
Metals mg/Kg												
Mercury	0.07				0.097				0.075			
Aluminum	15000	E,B			12000				11000			
Antimony	<MDL,G		1		<MDL,G		5		1.5	G		
Arsenic	4.2	E,G			13				6	E		
Barium	38	E,B			40				33	B		
Beryllium	0.14	E			0.32				0.3			
Cadmium	<MDL,E		0.3		<MDL		0.3		0.15	E		
Chromium	12	E,B			16	E			14			
Copper	9.6	E,B			19	B			18			
Iron	15000	E			23000				16000			
Lead	5.6	E			15				13			
Nickel	9.9	E			15				13			
Selenium	<MDL,G		1		<MDL		8		<MDL		3	
Silver	<MDL,E		0.3		0.65				0.75			
Thallium	<MDL,E		3		<MDL		30		9			
Zinc	41	E			60	B			54			

In 1990 antimony, arsenic, selenium, and thallium were analyzed using GFAA methods. See Appendix E.

<RDL - Detected below quantification limits

<MDL - Undetected at the method detection limit

B - Blank contamination

G - Low standard reference material recovery

L - High standard reference material recovery

E - Estimate based on high relative percent difference in duplicate, high relative standard deviation in triplicate, or high or low surrogate recoveries

TABLE 5-2 (continued). Stations L, M, and S: Organic Compounds and Metals

Station/Locator	M LTBD23				M LTBD23				M LTBD23			
Date Sampled	Apr 03, 90				May 30, 91				May 26, 92			
Sample Number	9000330				9101188				9201095			
% Solids:	75				73				71			
% TOC	0.13				0.69				1.3			
BNA Organics (µg/kg dry)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs												
Naphthalene	<MDL		10	33	<MDL		40	68	<MDL		40	70
Acenaphthylene	<MDL		5	11	<MDL		10	23	<MDL		10	24
Acenaphthene	<MDL		4	8.9	<MDL		10	18	<MDL		10	18
Fluorene	<MDL		5	11	<MDL		10	23	10	<RDL	10	24
Phenanthrene	12		5	11	38		10	23	120		10	24
Anthracene	<MDL		5	11	41		10	23	150		10	24
HPAHs												
Fluoranthene	19		7	13	66		10	27	230		10	28
Pyrene	12		5	11	48		10	23	150		10	24
Benzo(a)anthracene	<MDL		5	11	38		10	23	110		10	24
Chrysene	<MDL		5	11	59		10	23	170		10	24
Benzo(b)fluoranthene	<MDL		10	33	<MDL		40	68	150		40	70
Benzo(k)fluoranthene	<MDL		10	33	<MDL		40	68	60	<RDL	40	70
Benzo(a)pyrene	<MDL		10	23	<MDL		30	45	89		30	46
Indeno(1,2,3-Cd)Pyrene	<MDL		10	23	<MDL		30	45	55		30	46
Dibenzo(a,h)anthracene	<MDL		10	33	<MDL		40	68	<MDL		40	70
Benzo(g,h,i)perylene	<MDL		10	23	<MDL		30	45	51		30	46
Other												
Benzyl Butyl Phthalate	<MDL		5	11	<MDL		10	23	<MDL		10	24
Bis(2-Ethylhexyl)Phthalate	<MDL		5	11	<MDL,B		10	23	310	B	10	24
Di-N-Butyl Phthalate	<MDL		10	23	<MDL,B		30	45	<MDL,B		30	46
Dibenzofuran	<MDL		10	23	<MDL		30	45	<MDL		30	46
Benzoic Acid	<MDL		40	67	<MDL		70	140	<MDL		70	140
Coprostanol									<MDL		70	140
Carbazole									<MDL		30	46
PCBs												
Aroclor 1248	<MDL		10	23	<MDL		10	23	<MDL		20	46
Aroclor 1254	<MDL		10	23	<MDL		10	23	52		20	46
Aroclor 1260	<MDL		10	23	<MDL		10	23	<MDL		20	46
Volatiles												
Acetone	<MDL		40	67	<MDL		10	27	<MDL		40	70
Metals mg/Kg												
Mercury	0.04				0.055				0.73			
Aluminum	7600	E,B			9200				8500			
Antimony	<MDL,G		1		<MDL,G		4		1.4	G		
Arsenic	4	E,G			9.6				7	E		
Barium	28	E,B			27				28	B		
Beryllium	0.27	E			0.27				0.28			
Cadmium	<MDL		0.4		<MDL		0.5		0.13	E		
Chromium	11	E			13	E			12			
Copper	7.9	E,B			14	B			17			
Iron	16000	E,B			19000				17000			
Lead	5.3	E			9.6				8.7			
Nickel	9.3	E			12				11			
Selenium	<MDL,G		1		<MDL		7		<MDL		1	
Silver	<MDL		0.4		<MDL		0.4		0.7			
Thallium	<MDL,E		3		<MDL		30		11			
Zinc	39	E			45	B			46			

In 1990 antimony, arsenic, selenium, and thallium were analyzed using GFAA methods. See Appendix E.

<RDL - Detected below quantification limits

<MDL - Undetected at the method detection limit

B - Blank contamination

G - Low standard reference material recovery

L - High standard reference material recovery

E - Estimate based on high relative percent difference in duplicate, high relative standard deviation in triplicate, or high or low surrogate recoveries

1990 Results

TABLE 5-2 (continued). Stations L, M, and S: Organic Compounds and Metals

Station/Locator	S LTBD25				S LTBD25				S LTBD25			
Date Sampled	Apr 26, 90				Jun 13, 91				Jul 01, 92			
Sample Number	9000395				9101268				9201379			
% Solids:	77				79				75			
% TOC	0.78				1.7				0.47			
BNA Organics (µg/kg dry)	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL	Value	Qual	MDL	RDL
LPAHs												
Naphthalene		<MDL	50	97		<MDL	40	63		<MDL	30	67
Acenaphthylene		<MDL	20	32		<MDL	10	22		<MDL	10	23
Acenaphthene	91		10	26	71		9	16		<MDL	9	17
Fluorene	87		20	32	91		10	22		<MDL	10	23
Phenanthrene	730		20	32	840		10	22	190		10	23
Anthracene	110		20	32	120		10	22	37		10	23
HPAHs												
Fluoranthene	1300		20	39	350		10	25	360		10	27
Pyrene	650		20	32	630		10	22	270		10	23
Benzo(a)anthracene	390		20	32	460		10	22	120		10	23
Chrysene	520		20	32	510		10	22	120		10	23
Benzo(b)fluoranthene	390		50	97	480		40	63	170		30	67
Benzo(k)fluoranthene	290		50	97	410		40	63	190		30	67
Benzo(a)pyrene	400		30	65	380		30	42		<MDL	20	44
Indeno(1,2,3-Cd)Pyrene	170		30	65	160		30	42		<MDL	20	44
Dibenzo(a,h)anthracene		<MDL	50	97		<MDL	40	63		<MDL	30	67
Benzo(g,h,i)perylene	130		30	65	130		30	42		<MDL	20	44
Other												
Benzyl Butyl Phthalate	82		20	32	140		10	22		<MDL	10	23
Bis(2-Ethylhexyl)Phthalate	2900		20	32	1800		10	22	870		10	23
Di-N-Butyl Phthalate		<MDL	30	65		<MDL	30	42		<MDL,B	20	44
Dibenzofuran		<MDL	30	65	47		30	42		<MDL	20	44
Benzoic Acid	300		100	190		<MDL	60	130		<MDL	70	130
Coprostanol										<MDL	70	130
Carbazole									56		20	44
PCBs												
Aroclor 1248		<MDL	60	110		<MDL	30	42		<MDL	20	44
Aroclor 1254		<MDL	60	110	52		30	42	40	<RDL	20	44
Aroclor 1260		<MDL	60	110		<MDL	30	42		<MDL	20	44
Volatiles												
Acetone	110		40	65		<MDL	6	13		<MDL	40	67
Metals mg/Kg												
Mercury	1.3				0.57				0.71			
Aluminum	7700	B,E			7700				5300			
Antimony	9.1	E,G			6.3	G			4	G		
Arsenic	6.5	G			7.6				5.3			
Barium	48	B			48				24			
Beryllium	0.12	E			0.25				0.08			
Cadmium	1.4	E,G,L			1.3				1.5			
Chromium	45	B,E			38	E			21	G		
Copper	700	E,G			410	B			130			
Iron	13000	B			14000				8900			
Lead	390	E			700				280			
Nickel	38				37				32	G		
Selenium	0.91					<MDL	6			<MDL	3	
Silver	6	L			19				11			
Thallium		<MDL,E,G	3			<MDL	30			<MDL	4	
Zinc	380	B,G,E			230	B			170	G		

In 1990 antimony, arsenic, selenium, and thallium were analyzed using GFAA methods. See Appendix E.

<RDL - Detected below quantification limits

<MDL - Undetected at the method detection limit

B - Blank contamination

G - Low standard reference material recovery

L - High standard reference material recovery

E - Estimate based on high relative percent difference in duplicate, high relative standard deviation in triplicate, or high or low surrogate recoveries

but always well below the SQS. Metals concentrations were usually at least an order of magnitude lower than the SQS.

As expected, the composition of organic compounds and metals in the 1990 surface grab samples was very similar to the cores and pre-dredge samples. Table 5-3 summarizes the average concentrations of the PAHs and metals that were detected in the surface grabs, cores, and pre-dredge analyses. The comparison was complicated by the unexpected presence of mud found in core section P3, compounds and metals that were not always detected, and metals that were not analyzed for in the pre-dredge analysis.

The clay in P3 biased the average concentrations of organic compounds within the core samples. The mud appeared to be native river mud with naturally higher levels of organics and metals concentrations than are present in river sand. Excluding P3, the detected concentrations of compounds in the

TABLE 5-3. Average Concentrations in 1989 and 1990 Samples				
	Grabs	All Cores	Cores w/o P3	Pre-dredge
Phenanthrene	28	66	31	19
Fluoranthene	38	95	39	28
Pyrene	28	66	32	35
Benzo (a) anthracene	13	< 46	< 29	11
Chrysene	17	< 59	< 30	17
Benzo (b) fluoranthene	24	< 119	< 95	20
Benzo (k) fluoranthene	25	< 115	< 95	23
Benzo (a) pyrene	18	< 82	< 63	16
Aluminum	8,500	9,933	9,382	
Arsenic	5	5	5	7
Beryllium	0.21	0.18	0.16	
Cadmium	0.31	0.27	0.26	0.13
Chromium	13	14	13	
Copper	9	12	11	18
Iron	16,250	19,083	18,636	
Lead	8	8	7	11
Manganese	188	220	213	
Mercury	0.06	0.05	0.05	0.03
Nickel	10	13	13	30
Zinc	40	52	50	91

1990 Results

cores, grabs, and pre-dredge samples were undifferentiated. The average concentrations of metals were low and consistent in the cores, grabs, and pre-dredge samples, apparently less influenced by the mud in P3. Five PAHs were detected in the grabs and pre-dredge samples but were usually undetected in the core samples because of higher detection limits. The average concentrations of these five compounds (benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(a)pyrene) in the grabs and pre-dredge samples were nearly identical.

The fewest compounds and the lowest concentrations were found at the southernmost station (M), but the differences in composition between stations were not pronounced (see Figures 5-1 to 5-3). Stations K and L shared the same composition of organic compounds, while slightly fewer PAHs were detected at J. The spatial differences in the 1990 baseline samples were unrelated to any potential influence from the outfall because the cap was installed only a week prior to sampling. The lower concentrations at M could be the result of the lower organic carbon content (0.13 percent vs. 0.63-1.24 percent) and the higher percentage of sand (98 percent) at M relative to the other three sites (93 percent). While values at Station M were a factor of 2 or 3 lower than stations J and K, the values at all stations were near the detection limit, so the differences were considered nonsignificant and reflect natural variability of the capping sands.

All of the concentrations on the cap surface were well below the SQS (see Table 5-4). Detection limits for dry-weight-based criteria and metals were lower than the SQS. Detection limits for TOC-normalized samples exceeded the SQS in a few instances, primarily because of the low carbon content of samples.

1990 Station S

The composition of chemical contaminants at Station S was similar to that of the below-cap sediments. Of the 20 semivolatile organic compounds found below the cap, 16 were detected at Station S. No pesticides or PCBs were identified at Station S. PAHs at Station S were always within the same range or lower than the concentrations in the below-cap samples from the 1990 cores. Most metals concentrations at S were also within the same range or lower, while concentrations of three metals were higher at S than in the below-cap values.

Because of the proximity of the stations to the outfall one might expect Station S to have higher chemical concentrations or more occurrences than the subtidal capped sediments. Instead, concentrations at S were lower than or

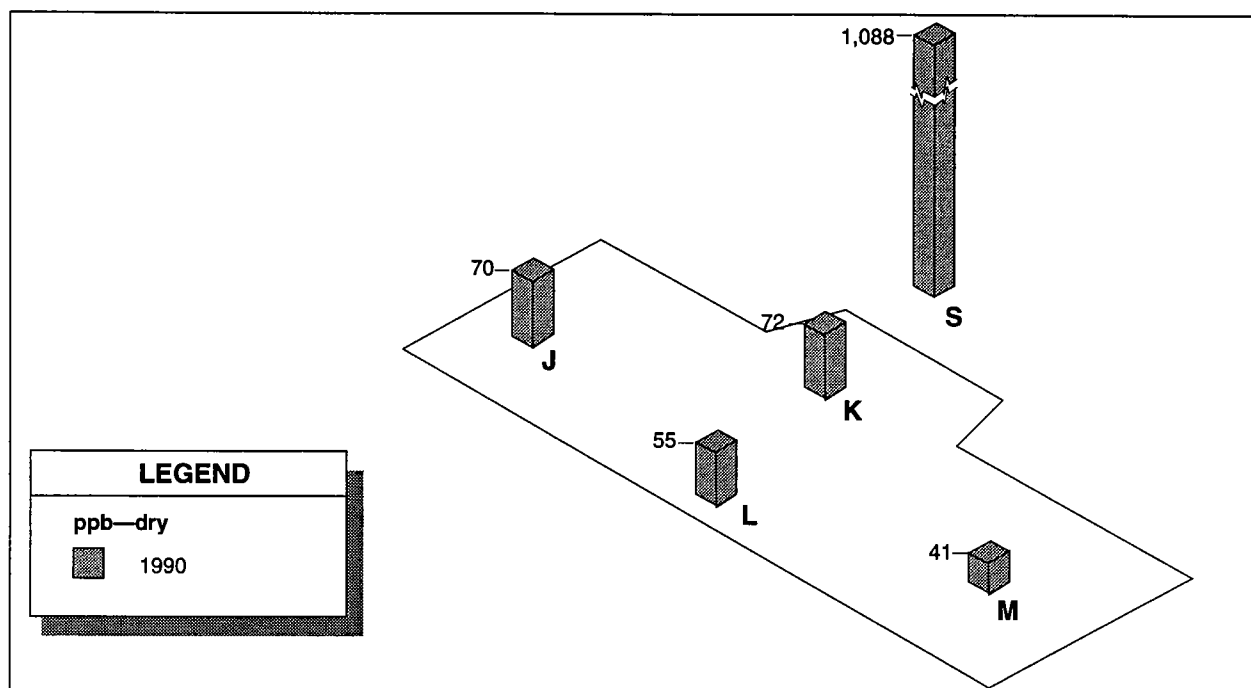


Figure 5-1 1990 Spatial Concentrations of LPAHs Figure

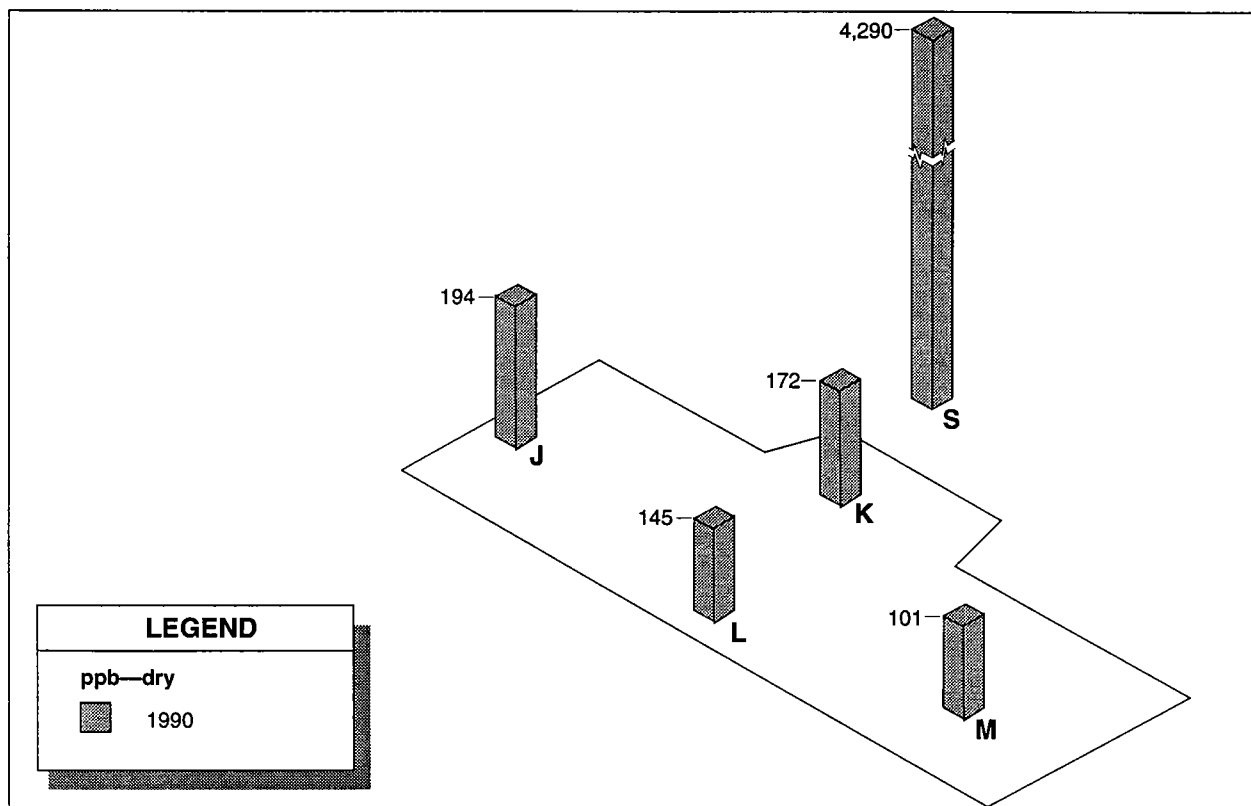


Figure 5-2. 1990 Spatial Concentrations of HPAHs

1990 Results

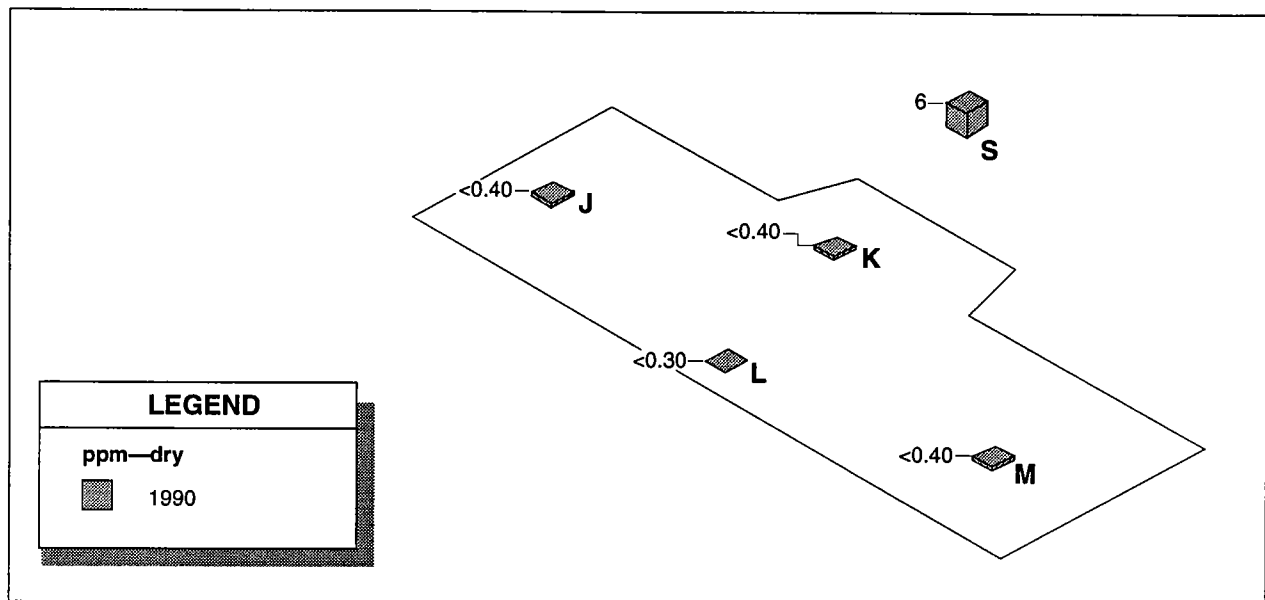


Figure 5-3. 1990 Spatial Concentrations of Silver

within the same range as below-cap values at core Stations N and P and lower than the below-cap values for the coring site nearest the shore (Station O). Chemical concentrations and occurrences were lower at the intertidal Station S than the subtidal, below-cap samples because finer, more contaminated sediments do not accumulate in the high energy, intertidal zone. The intertidal station was 96 percent sand: 3 percent silt: 1 percent clay, much like the surface and within-cap sediments. The below-cap sediments were much different, composed of roughly 33 percent sand: 53 percent silt: 14 percent clay. Organic compounds and metals bind to finer sediments more readily, and finer sediments cannot accumulate in the intertidal zone.

The concentrations of antimony, copper, and zinc were higher at S than anywhere else in 1990, including beneath the cap. Cadmium, chromium, lead, manganese, mercury, and silver concentrations were within the same range as found in the contaminated sediments beneath the cap. The Station S concentrations of aluminum, arsenic, beryllium, iron, nickel, and selenium were lower than the lowest below-cap concentrations. Thallium was not detected at S or below the cap. Copper and mercury at S exceeded the CSL. Lead, silver, and zinc were slightly below the SQS.

TABLE 5-4. 1990 Comparison to Sediment Standards

Station/Locator	J LTBC20		K LTBC34		L LTBC35		Sediment Management Standards	
Date Sampled	Apr 03, 90		Apr 03, 90		Apr 03, 90			
Sample Number	9000327		9000328		9000329			
% Solids	69		72		71			
% TOC	1.2		0.97		0.63		SQS Table I	CSL Table III
Parameters	Value	Qual	Value	Qual	Value	Qual		
LPAHs (mg/kg OC)								
Naphthalene	0.8	<MDL	1	<MDL	2	<MDL	99	170
Acenaphthene	0.3	<MDL	0.4	<MDL	0.6	<MDL	16	57
Acenaphthylene	0.5	<MDL	0.6	<MDL	1	<MDL	66	66
Phenanthrene	3.2		4.1		3.7		100	480
Fluorene	0.5	<MDL	0.6	<MDL	1	<MDL	23	79
Anthracene	0.5	<MDL	0.6	<MDL	1	<MDL	220	1,200
2-Methylnaphthalene	0.8	<MDL	1	<MDL	2	<MDL	38	64
Total LPAHs	6.6		8.3		11.3		370	780
HPAHs (mg/kg OC)								
Fluoranthene	4.1		5.1		5.6		160	1,200
Pyrene	3.4		3.4		4.3		1,000	1,400
Benzo(a)anthracene	1.6		1.5		1	<MDL	110	270
Chrysene	2.1		1.5		2.7		110	460
Total benzofluoranthenes	1.6		2		4		230	450
Benzo(a)pyrene	0.8	<MDL	1	<MDL	2	<MDL	99	210
Indeno(1,2,3-Cd)Pyrene	0.8	<MDL	1	<MDL	2	<MDL	34	88
Dibenzo(a,h)anthracene	0.8	<MDL	1	<MDL	2	<MDL	12	33
Benzo(g,h,i)perylene	0.8	<MDL	1	<MDL	2	<MDL	31	78
Total HPAHs	16		17.5		25.6		960	5,300
Other (mg/kg OC)								
1,2-Dichlorobenzene	0.5	<MDL	0.6	<MDL	1	<MDL	2.3	2.3
1,4-Dichlorobenzene	0.5	<MDL,G	0.6	<MDL,G	1	<MDL,G	3.1	9
1,2,4-Trichlorobenzene	0.5	<MDL	0.6	<MDL	1	<MDL	0.81	1.8
Hexachlorobenzene	0.5	<MDL	0.6	<MDL	1	<MDL	0.38	2.3
Diethyl Phthalate	0.8	<MDL	1	<MDL	2	<MDL	61	110
Dimethyl Phthalate	0.3	<MDL	0.4	<MDL	0.6	<MDL	53	53
Di-N-Butyl Phthalate	0.8	<MDL	1	<MDL	2	<MDL	220	1,700
Benzyl Butyl Phthalate	0.5	<MDL	0.6	<MDL	1	<MDL	4.9	64
Bis(2-Ethylhexyl)Phthalate	4.8		13		7		47	78
Di-N-Octyl Phthalate	0.5	<MDL	0.6	<MDL	1	<MDL	58	4,500
Dibenzofuran	0.8	<MDL	1	<MDL	2	<MDL	15	58
Hexachlorobutadiene	0.8	<MDL	1	<MDL	2	<MDL	3.9	6.2
N-Nitrosodiphenylamine	0.8	<MDL	1	<MDL	2	<MDL	11	11
Total PCBs	0.8	<MDL	1	<MDL	2	<MDL	12	65
Other (dry weight µg/kg)								
Phenol	40	<MDL	40	<MDL	40	<MDL	420	1,200
2-Methylphenol	10	<MDL	10	<MDL	10	<MDL	63	63
4-Methylphenol	10	<MDL	10	<MDL	10	<MDL	670	670
2,4-Dimethylphenol	10	<MDL	10	<MDL	10	<MDL	29	29
Pentachlorophenol	10	<MDL	10	<MDL	10	<MDL	360	690
Benzyl Alcohol	10	<MDL	10	<MDL	10	<MDL	57	73
Benzoic Acid	140		110		110		650	650
Metals (mg/kg dry weight)								
Mercury	0.058		0.056		0.07		0.41	0.59
Arsenic	5.8	E,G	4.2	E,G	4.2	E,G	57	93
Cadmium	0.3	<MDL,E	0.3	<MDL,E	0.3	<MDL,E	5.1	6.7
Chromium	14	E,B	13	E,B	12	E,B	260	270
Copper	11	E,B	9.9	E,B	9.6	E,B	390	390
Lead	7.2	E	14	E	5.6	E	450	530
Silver	0.4	<MDL, E	0.4	<MDL,E	0.3	<MDL,E	6.1	6.1
Zinc	49	E	47	E	41	E	410	960
				Exceeds SQS	Exceeds CSL			

1990 Results

TABLE 5-4 (continued). 1990 Comparison to Sediment Standards

Station/Locator	M LTBD23		S LTBD25		Sediment Management Standards	
Date Sampled	Apr 03, 90		Apr 26, 90			
Sample Number	9000330		9000395			
% Solids	75		77			
% TOC	0.13		0.78		SQS Table I	CSL Table III
Parameters	Value	Qual	Value	Qual		
LPAHs (mg/kg OC)						
Naphthalene	8	<MDL	6	<MDL	99	170
Acenaphthene	3	<MDL	12		16	57
Acenaphthylene	4	<MDL	3	<MDL	66	66
Phenanthrene	9.2		94		100	480
Fluorene	4	<MDL	11		23	79
Anthracene	4	<MDL	14		220	1,200
2-Methylnaphthalene	8	<MDL	6	<MDL	38	64
Total LPAHs	40.2		146		370	780
HPAHs (mg/kg OC)						
Fluoranthene	15		170		160	1,200
Pyrene	9.2		83		1,000	1,400
Benzo(a)anthracene	4	<MDL	50		110	270
Chrysene	4	<MDL	67		110	460
Total benzofluoranthenes	16		87		230	450
Benzo(a)pyrene	8	<MDL	51		99	210
Indeno(1,2,3-Cd)Pyrene	8	<MDL	22		34	88
Dibenzo(a,h)anthracene	8	<MDL	6	<MDL	12	33
Benzo(g,h,i)perylene	8	<MDL	17		31	78
Total HPAHs	80.2		553		960	5,300
Other (mg/kg OC)						
1,2-Dichlorobenzene	4	<MDL	3	<MDL	2.3	2.3
1,4-Dichlorobenzene	4	<MDL,G	3	<MDL	3.1	9
1,2,4-Trichlorobenzene	4	<MDL	3	<MDL	0.81	1.8
Hexachlorobenzene	4	<MDL	3	<MDL	0.38	2.3
Diethyl Phthalate	8	<MDL	4	<MDL	61	110
Dimethyl Phthalate	3	<MDL	1	<MDL	53	53
Di-N-Butyl Phthalate	8	<MDL	4	<MDL	220	1,700
Benzyl Butyl Phthalate	4	<MDL	11		4.9	64
Bis(2-Ethylhexyl)Phthalate	4	<MDL	370		47	78
Di-N-Octyl Phthalate	4	<MDL	3	<MDL	58	4,500
Dibenzofuran	8	<MDL	4	<MDL	15	58
Hexachlorobutadiene	8	<MDL	4	<MDL	3.9	6.2
N-Nitrosodiphenylamine	8	<MDL	4	<MDL	11	11
Total PCBs	8	<MDL	8	<MDL	12	65
Other (dry weight µg/kg)						
Phenol	40	<MDL	100	<MDL	420	1,200
2-Methylphenol	10	<MDL	30	<MDL	63	63
4-Methylphenol	10	<MDL	30	<MDL	670	670
2,4-Dimethylphenol	10	<MDL	30	<MDL	29	29
Pentachlorophenol	10	<MDL	30	<MDL,L	360	690
Benzyl Alcohol	10	<MDL	30	<MDL	57	73
Benzoic Acid	40	<MDL	300		650	650
Metals (mg/kg dry weight)						
Mercury	0.04		1.3		0.41	0.59
Arsenic	4	E,G	6.5	G	57	93
Cadmium	0.4	<MDL	1.4	E,G,L	5.1	6.7
Chromium	11	E	45	B,E	260	270
Copper	7.9	E,B	700	E,G	390	390
Lead	5.3	E	390	E	450	530
Silver	0.4	<MDL	6	L	6.1	6.1
Zinc	39	E	380	B,G,E	410	960
Exceeds SQS			Exceeds CSL			

Comparisons of Station S to the on-cap and within-cap samples were possible because the particle size composition of the intertidal sample was similar to the surface and within-cap samples. The levels of contamination at S of eight PAHs were 12 to 34 times higher than the mean concentration from the four grab samples. The range of differences in metals concentration was larger but also less constant; six metals were lower, within the same range, or only slightly higher at S than the average cap concentration. Other metals concentrations ranged from 4 to 80 times higher at S than the on-cap average. Concentrations at Station S were also much higher than the average within-cap concentrations.

At intertidal Station S, bis(2-ethylhexyl)phthalate, copper and mercury exceeded the CSL. Fluoranthene and benzyl butyl phthalate exceeded the SQS. Acenaphthene, phenanthrene, lead, silver, and zinc approached the SQS. The detection limits for six compounds (1,2-dichlorobenzene, 1,4-dichloro-benzene, 1,2,4-trichlorobenzene, hexachlorobenzene, hexachlorobutadiene, total PCBs) exceeded the TOC-based SQS and, in some cases, the CSL. Dry-weight-based SQS and CSL were exceeded by detection limits for 2-methylphenol, 2,4-dimethylphenol and benzyl alcohol. It is common for highly contaminated samples to have high detection limits because it is more difficult to reduce the "background noise" within the analysis.

1991 RESULTS

During subsequent sampling years, the monitoring plan required chemical changes to be identified and displayed, any spatial differences to be related to possible sources, potential sources to be evaluated for control actions if there were significant increases, and comparison to the SMS. The vertical profile plots in Section 4 show how representative chemicals have increased in samples collected in 1991 one year after cap placement.

Summary

All of the subtidal stations experienced increases in the number of compounds detected and increases in the concentrations of previously detected compounds. At least six PAHs were detected at all four stations in 1991, compared to three PAHs in 1990. The average concentration of previously detected PAHs increased two- to eight-fold. Average metals concentrations increased at slower rates than the PAHs. Silver was detected at the three northern sites. Trace amounts of one PCB appeared at J and K. Pesticides and volatile

1991 Results

organics were undetected. The intertidal uncapped site, Station S, was largely unchanged from 1990.

In 1990, the cap surface was reasonably homogeneous. In 1991, distinct spatial differences developed in the distribution of PAHs. The on-cap station closest to the outfall and shore (K) showed the largest increases. Stations seaward (L) and north (J) of K were subject to lower but still showed considerable increases. The station to the south (M) was the least changed.

Spatial differences in the distribution of metals were not as apparent. All four stations showed increases. In general, the three northern stations had similar metals composition, with concentrations only slightly higher than those found at the southernmost station.

Video camera surveys conducted in 1990 (see Section 6) showed a layer of fine silt mixed with organic debris and plant growth that in some areas appeared to increase in thickness in subsequent surveys in 1991 and 1992. The same layer was also noted in the sediment-profile camera survey (see Appendix D). The contamination found on the cap in 1991 was presumably sorbed to the fine material. The two most likely sources of the contaminated fine sediments were solids discharged from the outfall or contaminated nearshore sediments redistributed onto the cap. To determine the dominant source, both CSO wastewater samples and additional nearshore sediment sampling is being planned for future years. All organic compounds detected on the cap except one were below the SQS.

One compound, bis(2-ethylhexyl)phthalate, exceeded the CSL at K where concentrations had increased and the TOC levels remained low at 0.52 percent. In 1992 at K, this compound was below the SQS even though the dry-weight concentration increased because the TOC had increased.

Specifics

In 1991, more compounds and metals were detected and concentrations were higher on the cap surface than in 1990. Only phenanthrene, fluoranthene, and pyrene were detected at all four stations in 1990. In 1991, these and anthracene, fluoranthene, pyrene, and benzo(a)anthracene were found at all four on-cap stations. Two previously detected compounds behaved erratically; bis(2-ethylhexyl) phthalate disappeared from J but increased at K and L, while benzoic acid, previously detected at the three northernmost stations, was not detected anywhere.

The average concentrations of all metals were higher in 1991 than 1990. Silver was detected at the three northernmost sites, while remaining undetected at Station M. Antimony, cadmium, selenium, and thallium remained undetected.

Figures 5-4 to 5-6 demonstrate the spatial distribution of total LPAHs, total HPAHs, and lead for 1991. The highest concentrations of all detected organic compounds except Aroclor 1254 were found at Station K, the station closest to the outfall and the contaminated nearshore sediments. Station L, which is farthest offshore but nearest Station K, had the second highest concentrations for all PAHs. Stations J, K, and L had nearly identical concentrations of all detected metals and each of these three stations had the highest concentration of several metals. Station M had the lowest concentration of each metal, but often the concentration was not much lower than that found at the other three stations.

Station K, the site closest to the shore and the outfall, experienced the largest increases in concentrations of organic compounds. Twelve PAHs were detected in 1991, compared to five the previous year. Among PAHs detected both years, the average increase was 170 ppb with a range of increases from 135 ppb to 300 ppb. Seven PAHs, one PCB, and silver were detected in 1991 that were not detected at this site in 1990. Most of the largest increases for metals were not at this site; only the increases of mercury and silver were greatest here.

Station L showed most of the largest increases for metals and the second largest increases for PAHs. The range of PAH increases was from 97 ppb to 175 ppb, with an average increase of 120 ppb. Six more PAHs (10 in 1991), and silver were detected in addition to those detected in 1990. The changes in concentrations for aluminum, arsenic, beryllium, chromium, iron, lead, manganese, nickel, and zinc were largest at this site, resulting in final metals concentrations that were comparable to those at J and K.

At J, the magnitude of increases in PAH concentrations was less than one-half the increases at K and about two-thirds the increase at L. The increase in PAHs averaged only 80 ppb, ranging from 45 ppb to 121 ppb. Eight PAHs were detected, versus five in 1990. Copper was the only parameter to exhibit the largest increase at J, but the change was suspiciously large and was probably caused by copper contamination in the method blank. The concentration (62 ppm-dry) was three times higher than anywhere else on the cap and was in the same range as the contaminated sediments below the cap. In 1992, the copper concentration dropped to 18 ppm-dry and was consistent with the other stations.

1991 Results

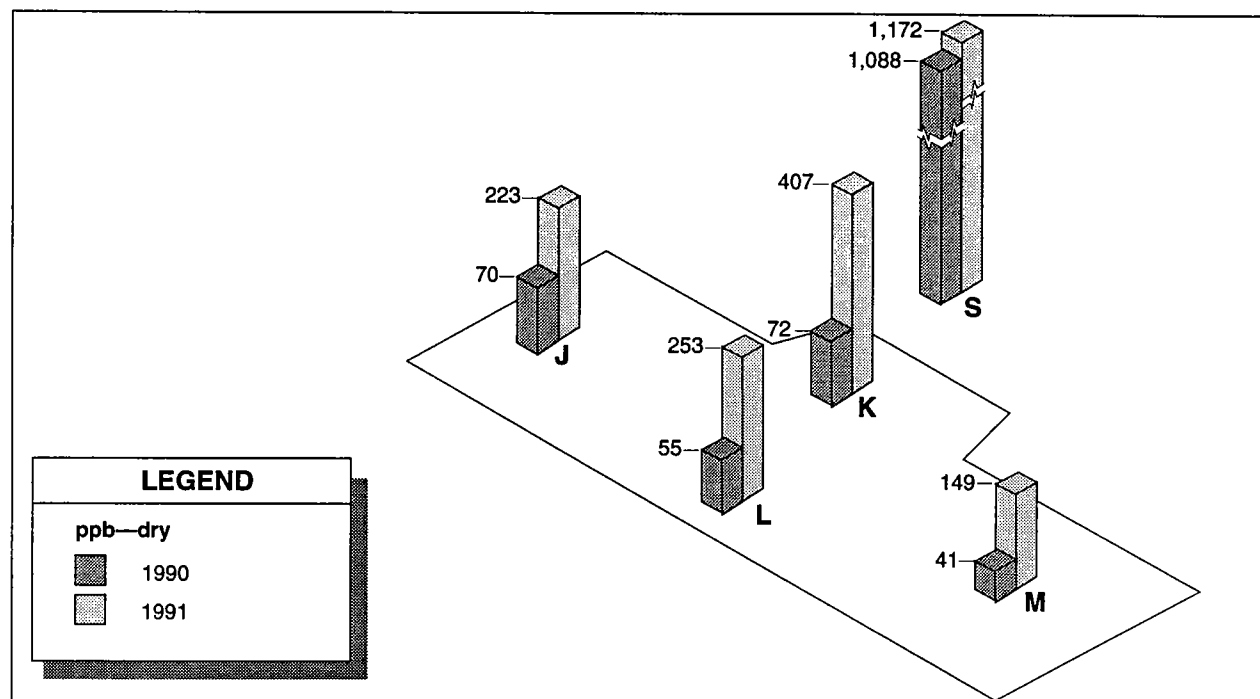


Figure 5-4. 1990 and 1991 Spatial Concentrations of LPAHs

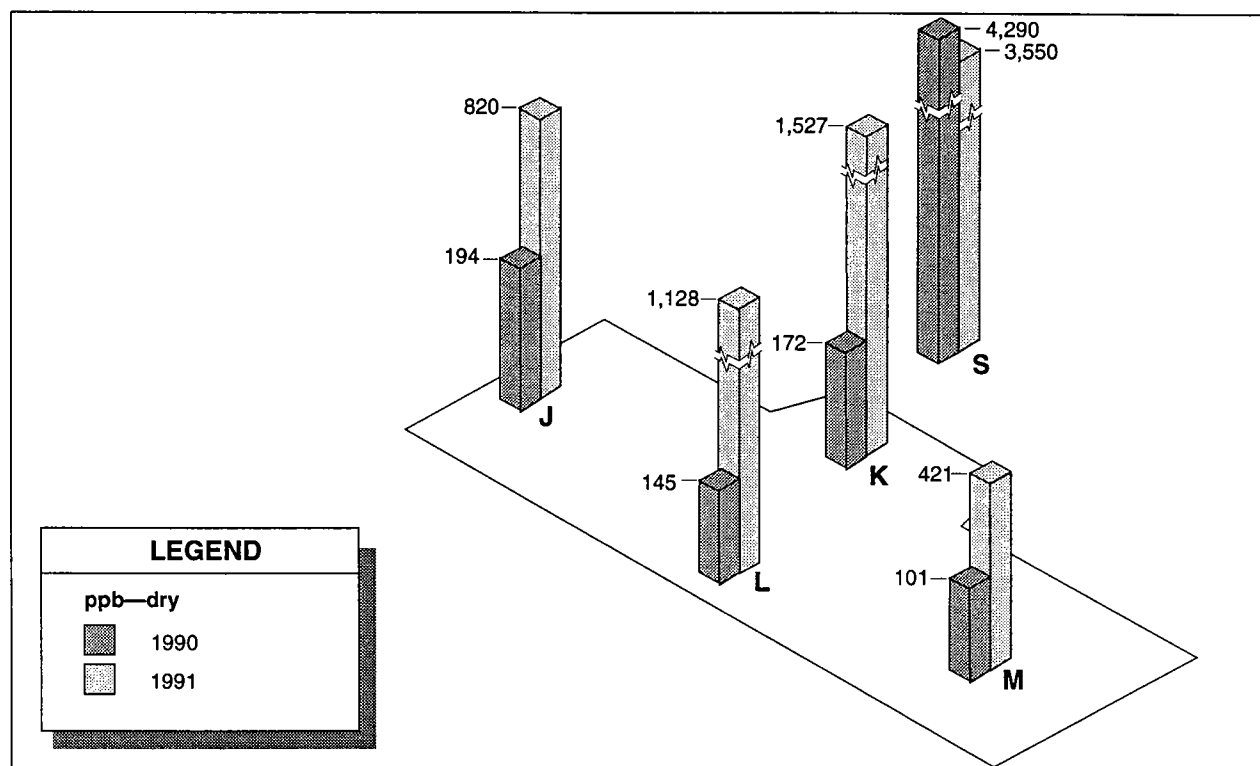


Figure 5-5. 1990 and 1991 Spatial Concentrations of HPAHs

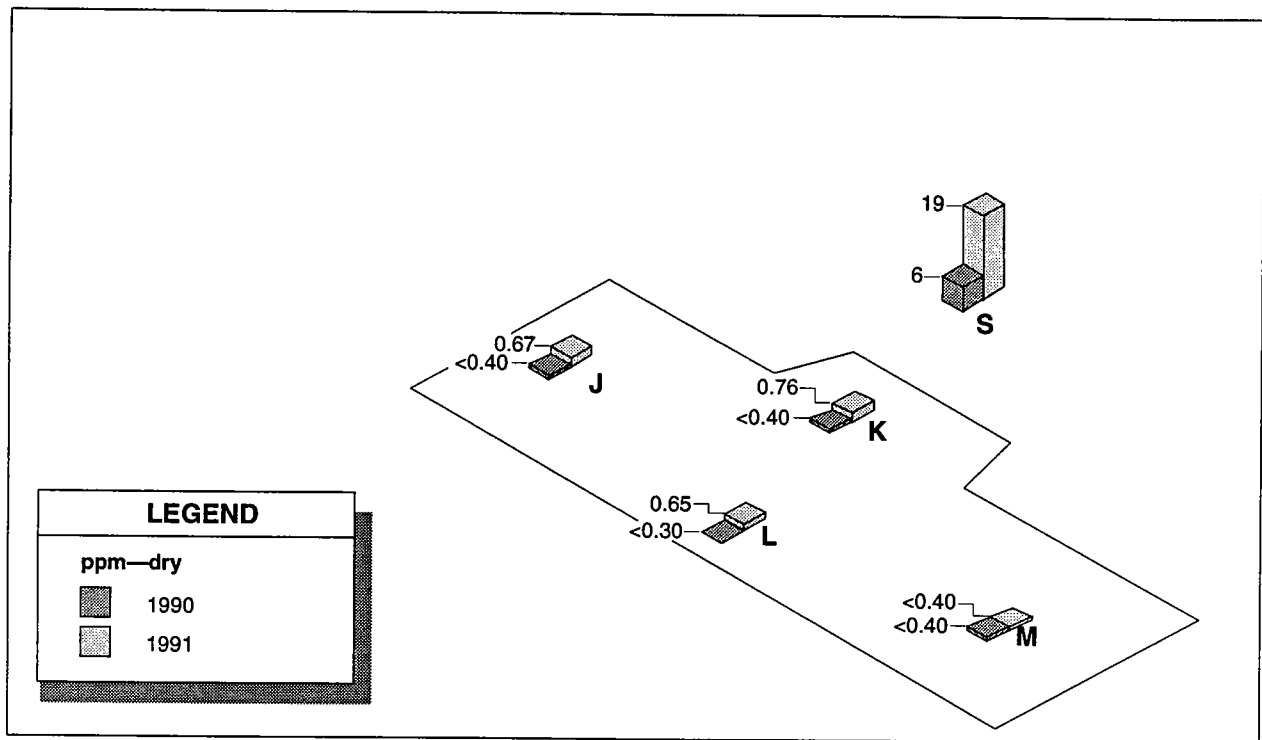


Figure 5-6. 1990 and 1991 Spatial Concentrations of Silver

At M, the change in PAH concentrations were the lowest anywhere, averaging an increase of 38ppb (range 26-47ppb) among compounds detected both years. Only three more PAHs (six versus three) were detected compared to 1990.

Fine material was deposited onto the cap between 1990 and 1991, as evidenced by the increase in the percentages of silt and clay present in the surface samples. In 1990, samples from J, K and L were composed of roughly 93 percent sand, 4-5 percent silt, and 2 percent clay. The 1990 sample from M was 98 percent sand, 2 percent silt, and a trace amount of clay. In 1991, the samples from the four stations contained 81 to 88 percent sand, 9 to 15 percent silt, and 5 to 6 percent clay. Overall, the percentage of mud (silt + clay) increased from a 1990 high of 7 percent to a 1991 range of 15 to 20 percent. The increases in surface contaminant concentrations were probably the result of contaminants that sorbed to the new finer sediments. However, the station with the highest concentrations (K) did not have the highest mud fraction, nor did the least contaminated (M) have the highest sand fraction, so there must be other factors in addition to sorption of contaminants to fine particles to account for the spatial differentiation.

1991 Results

When 1992 sample data for detected chemicals were compared with the SMS all but one were below the SQS and all were below the CSL. Bis(2-ethylhexyl)phthalate exceeded the CSL, at K (see Table 5-5). This exceedance occurred because the chemical level doubled, and the TOC value was halved, from the 1990 levels. The measured TOC value seemed low and more reflective of the capping material when it was placed in 1990. If the TOC value was over one percent, the phthalate level would be below the SQS. For several undetected compounds the detection limits exceeded the SMS.

All metals concentrations and detection limits were lower than the SQS. The method for analyzing arsenic, antimony, selenium and thallium changed from graphite furnace to ICP, resulting in detection limits higher than the 1990 limits but still within the ranges necessary for interpretation (see Appendix E). Cadmium remained undetected at a detection limit similar to 1990 limits.

1991 Station S

At Station S, most changes in concentrations for organic compounds and metals between 1990 and 1991 were minor and would most likely be attributed to natural variability. However, the changes in concentration for some parameters were worth noting.

Fluoranthene, bis(2-ethylhexyl)phthalate and benzoic acid concentrations were substantially lower in 1991. Benzo(k)fluoranthene and benzyl butyl phthalate were noticeably higher compared to 1990. Trace quantities of three PCBs were detected in 1991 as a result of lower detection limits. Station S concentrations of other semivolatile organic compounds changed less than 25 percent between the two years. Bis(2-ethylhexyl)phthalate and benzyl butyl phthalate concentrations still exceeded the CSL and SQS, respectively.

Four metals concentrations exceeded the SMS in 1991, compared to two in 1990. Lead and silver concentrations were higher in 1991 and exceeded the CSL. Copper and mercury concentrations were lower in 1991, but copper remained above the CSL and mercury remained above the SQS. The concentration of zinc, which was slightly lower than the SQS in 1990, was even lower in 1991.

Arsenic and beryllium concentrations were slightly higher in 1991. Selenium was not detected as the result of a higher detection limit caused by a change in analytical methods. Thallium remained undetected. All other metals concentrations were the same as or lower than 1990 Station S values.

TABLE 5-5. 1991 Comparison to Sediment Standards

Station/Locator	J LTBC20		K LTBC21		L LTBC22		Sediment Management Standards	
Date Sampled	May 28, 91		May 30, 91		May 30, 91			
Sample Number	9101185		9101186		9101187		SQS Table I	CSL Table III
% Solids	60		66		62			
% TOC	0.81		0.52		0.78			
Parameters	Value	Qual	Value	Qual	Value	Qual		
LPAHs (mg/kg OC)								
Naphthalene	6	<MDL	10	<MDL	6	<MDL	99	170
Acenaphthene	1	<MDL	2	<MDL	1	<MDL	16	57
Acenaphthylene	3	<MDL	2	<MDL	1	<MDL	66	66
Phenanthrene	10		38		15		100	480
Fluorene	3	<MDL	5.2		1	<MDL	23	79
Anthracene	4.9		21		6.8		220	1,200
2-Methylnaphthalene	6	<MDL	10	<MDL	6	<MDL	38	64
Total LPAHs	33.9		88.2		36.8		370	780
HPAHs (mg/kg OC)								
Fluoranthene	21		67		27		160	1,200
Pyrene	16		50		23		1,000	1,400
Benzo(a)anthracene	11		29		15		110	270
Chrysene	12		38		19		110	460
Total benzofluoranthenes	18		48		30		230	450
Benzo(a)pyrene	9		25		13		99	210
Indeno(1,2,3-Cd)Pyrene	4	<MDL	15		7.7		34	88
Dibenzo(a,h)anthracene	6	<MDL	10	<MDL	6	<MDL	12	33
Benzo(g,h,i)perylene	4	<MDL	12		4	<MDL	31	78
Total HPAHs	101		294		144.7		960	5,300
Other (mg/kg OC)								
1,2-Dichlorobenzene	3	<MDL	2	<MDL	1	<MDL	2.3	2.3
1,4-Dichlorobenzene	3	<MDL	2	<MDL	1	<MDL	3.1	9
1,2,4-Trichlorobenzene	3	<MDL	2	<MDL	1	<MDL	0.81	1.8
Hexachlorobenzene	3	<MDL	2	<MDL	1	<MDL	0.38	2.3
Diethyl Phthalate	4	<MDL	6	<MDL	4	<MDL	61	110
Dimethyl Phthalate	1	<MDL	2	<MDL	1	<MDL	53	53
Di-N-Butyl Phthalate	4	<MDL,B	6	<MDL,B	4	<MDL,B	220	1,700
Benzyl Butyl Phthalate	3	<MDL	2	<MDL	1	<MDL	4.9	64
Bis(2-Ethylhexyl)Phthalate	3	<MDL,B	100	B	41	B	47	78
Di-N-Octyl Phthalate	3	<MDL	2	<MDL	1	<MDL	58	4,500
Dibenzofuran	4	<MDL	6	<MDL	4	<MDL	15	58
Hexachlorobutadiene	4	<MDL	6	<MDL	4	<MDL	3.9	6.2
N-Nitrosodiphenylamine	4	<MDL	6	<MDL	4	<MDL	11	11
Total PCBs	4		6.2		1	<MDL	12	65
Other (dry weight µg/kg)								
Phenol	80	<MDL	80	<MDL	80	<MDL	420	1,200
2-Methylphenol	30	<MDL	30	<MDL	30	<MDL	63	63
4-Methylphenol	30	<MDL	30	<MDL	30	<MDL	670	670
2,4-Dimethylphenol	30	<MDL	30	<MDL	30	<MDL	29	29
Pentachlorophenol	30	<MDL	30	<MDL	30	<MDL	360	690
Benzyl Alcohol	30	<MDL	30	<MDL	30	<MDL	57	73
Benzoic Acid	80	<MDL	80	<MDL	80	<MDL	650	650
Metals (mg/kg dry weight)								
Mercury	0.083		0.11		0.097		0.41	0.59
Arsenic	12		11		13		57	93
Cadmium	0.3	<MDL	0.3	<MDL	0.3	<MDL	5.1	6.7
Chromium	17	E	15	E	16	E	260	270
Copper	62	B	18	B	19	B	390	390
Lead	13		15		15		450	530
Silver	0.67		0.76		0.65		6.1	6.1
Zinc	63	B	64	B	60	B	410	960
				Exceeds SQS	Exceeds CSL			

1991 Results

TABLE 5-5 (continued). 1991 Comparison to Sediment Standards						
Station/Locator	M LTBD23		S LTBD25		Sediment Management Standards	
Date Sampled	May 30, 91		Jun 13, 91			
Sample Number	9101188		9101268			
% Solids	73		79			
% TOC	0.69		1.7		SQS Table I	CSL Table III
Parameters	Value	Qual	Value	Qual		
LPAHs (mg/kg OC)						
Naphthalene	6	<MDL	2	<MDL	99	170
Acenaphthene	1	<MDL	4.2		16	57
Acenaphthylene	1	<MDL	0.6	<MDL	66	66
Phenanthrene	5.5		49		100	480
Fluorene	1	<MDL	5.4		23	79
Anthracene	5.9		7.1		220	1,200
2-Methylnaphthalene	6	<MDL	2	<MDL	38	64
Total LPAHs	26.4		70.3		370	780
HPAHs (mg/kg OC)						
Fluoranthene	9.6		21		160	1,200
Pyrene	7		37		1,000	1,400
Benzo(a)anthracene	5.5		27		110	270
Chrysene	8.6		30		110	460
Total benzo(a)fluoranthenes	10	<MDL	52		230	450
Benzo(a)pyrene	4	<MDL	22		99	210
Indeno(1,2,3-Cd)Pyrene	4	<MDL	9.4		34	88
Dibenzo(a,h)anthracene	6	<MDL	2	<MDL	12	33
Benzo(g,h,i)perylene	4	<MDL	7.6		31	78
Total HPAHs	60.7		208		960	5,300
Other (mg/kg OC)						
1,2-Dichlorobenzene	1	<MDL	0.6	<MDL	2.3	2.3
1,4-Dichlorobenzene	1	<MDL	0.6	<MDL	3.1	9
1,2,4-Trichlorobenzene	1	<MDL	0.6	<MDL	0.81	1.8
Hexachlorobenzene	1	<MDL	0.6	<MDL	0.38	2.3
Diethyl Phthalate	4	<MDL	2	<MDL	61	110
Dimethyl Phthalate	1	<MDL	0.4	<MDL	53	53
Di-N-Butyl Phthalate	4	<MDL,B	2	<MDL	220	1,700
Benzyl Butyl Phthalate	1	<MDL	8.2		4.9	64
Bis(2-Ethylhexyl)Phthalate	1	<MDL,B	110		47	78
Di-N-Octyl Phthalate	1	<MDL	0.6	<MDL	58	4,500
Dibenzofuran	4	<MDL	2.8		15	58
Hexachlorobutadiene	4	<MDL	2	<MDL	3.9	6.2
N-Nitrosodiphenylamine	4	<MDL	2	<MDL	11	11
Total PCBs	1	<MDL	3.1		12	65
Other (dry weight µg/kg)						
Phenol	70	<MDL	60	<MDL	420	1,200
2-Methylphenol	30	<MDL	30	<MDL	63	63
4-Methylphenol	30	<MDL	30	<MDL	670	670
2,4-Dimethylphenol	30	<MDL	30	<MDL	29	29
Pentachlorophenol	30	<MDL	30	<MDL	360	690
Benzyl Alcohol	30	<MDL	30	<MDL	57	73
Benzoic Acid	70	<MDL	60	<MDL	650	650
Metals (mg/kg dry weight)						
Mercury	0.055		0.57		0.41	0.59
Arsenic	9.6		7.6		57	93
Cadmium	0.5	<MDL	1.3		5.1	6.7
Chromium	13	E	38	E	260	270
Copper	14	B	410	B	390	390
Lead	9.6		700		450	530
Silver	0.4	<MDL	19		6.1	6.1
Zinc	45	B	230	B	410	960
Exceeds SQS			Exceeds CSL			

The total organic carbon content at Station S in 1991 was about twice the 1990 value and appeared unusually high for a sediment composed mostly of sand. The samples from Station S were composed of roughly 96 percent sand and 4 percent mud (silt + clay) in both 1990 and 1991.

1992 RESULTS

The second annual monitoring of the four surface stations was conducted in May 1992, according to schedule, 25 months after capping. A field replicate was analyzed at Station K in addition to the regular composite samples taken at each station. The intertidal sample was collected 5 weeks later. Shortly thereafter, severe scouring of the contaminated intertidal sediments resulted when a major CSO discharge occurred at the Denny Way outfall. Another composite sample was collected in August of 1992 from Stations J and K to see if the scoured sediments had settled onto the cap.

Summary

Concentrations and the number of parameters detected continued to rise in 1992. At least 12 PAHs were detected at each station, up from six the year before. Three more metals, cadmium, antimony, and thallium, were detected for the first time at all four stations. At M, PAH concentrations rose more than they had between 1990 and 1991. Rates of PAH increases at the other three stations were lower than the previous year. Mercury and silver were the only metals to increase noticeably.

The spatial differentiation between stations was not as distinct in 1992 as in previous years. K continued to have the highest concentrations and the most compounds detected, but spatial differences between the other three stations became less pronounced. The most substantial increases occurred at M, changing the values to be more comparable to J and L. L showed the least amount of change. Much lower chemical concentrations at the intertidal station brought many of the values to within the same range as those found on the cap surface.

A large CSO discharge that scoured contaminated intertidal sediments did not appear to cause any measurable recontamination of the cap. Concentrations were unchanged or lower at one of the two stations where post-storm samples were collected. The other station did not appear to be significantly affected.

1992 Results

Specifics

The 1992 data showed PAH concentrations to be higher at all stations compared to the 1991 values. The number of PAH compounds detected at K went from 12 to 13 and L went from 10 to 12. The number of compounds increased to 12 at both Station J and M from 8 and 6, respectively. K continued to have the highest concentrations of most PAHs, but the differences between J, L, and M were not as pronounced (see Figures 5-7 to 5-9). Dibenzo(a,h) anthracene remained undetected at all stations.

Bis(2-ethylhexyl)phthalate increased at all four Stations. The distribution of bis(2-ethylhexyl)phthalate, from highest to lowest concentration, was K-J-L-M. Benzyl butyl phthalate was detected on the cap surface for the first time, at K. The one PCB detected on the cap surface in 1991, Aroclor 1254, increased at three stations, decreased at one station, but was not detected in the field replicate at K despite being detected in the regular sample. The Aroclor 1254 distribution from highest to lowest concentration was K-L-M, undetected at J, showing that the highest values were consistently near the outfall. The heterogeneity of PCB concentrations was observed in pre-cap sediment data collected at 20 stations in 1986 (Romberg et al. 1987). PCBs failed to show the typical concentration gradients that were observed for almost all other organics and metals.

Nearly all chemical levels were less than 10 percent of the SQS and many were less than 5 percent of the SQS. Only the three metals, mercury, arsenic, and silver, and three organics, bis(2-ethylhexyl)phthalate, benzyl butyl phthalate, and PCBs exceeded 10 percent of the SQS at certain stations.

Organic carbon content was higher in the 1992 samples than in the previous 2 years. As a result, no detected compounds and fewer detection limits exceeded the SQS (see Tables 5-6 and 5-7). Bis(2-ethylhexyl)phthalate values ranged from 25 percent of the SQS at M to 70 percent of the SQS at K. In 1991 the bis(2-ethylhexyl)phthalate concentration at K exceeded the CSL because of low TOC. The 1992 value is below the SQS because the TOC increased and compensated for an increase in dry-weight concentration. The butyl benzyl phthalate concentration at K was 15 percent of the SQS. For PCBs, only Aroclor 1254 was detected; it was undetected at J and ranged to 50 percent of the SQS at K. The detection limits for 1,2,4-trichlorobenzene and hexachlorobenzene regularly exceeded the TOC-normalized-based SQS. The detection limits for 2,4-dimethylphenol regularly exceeded the dry-weight-based CSL.

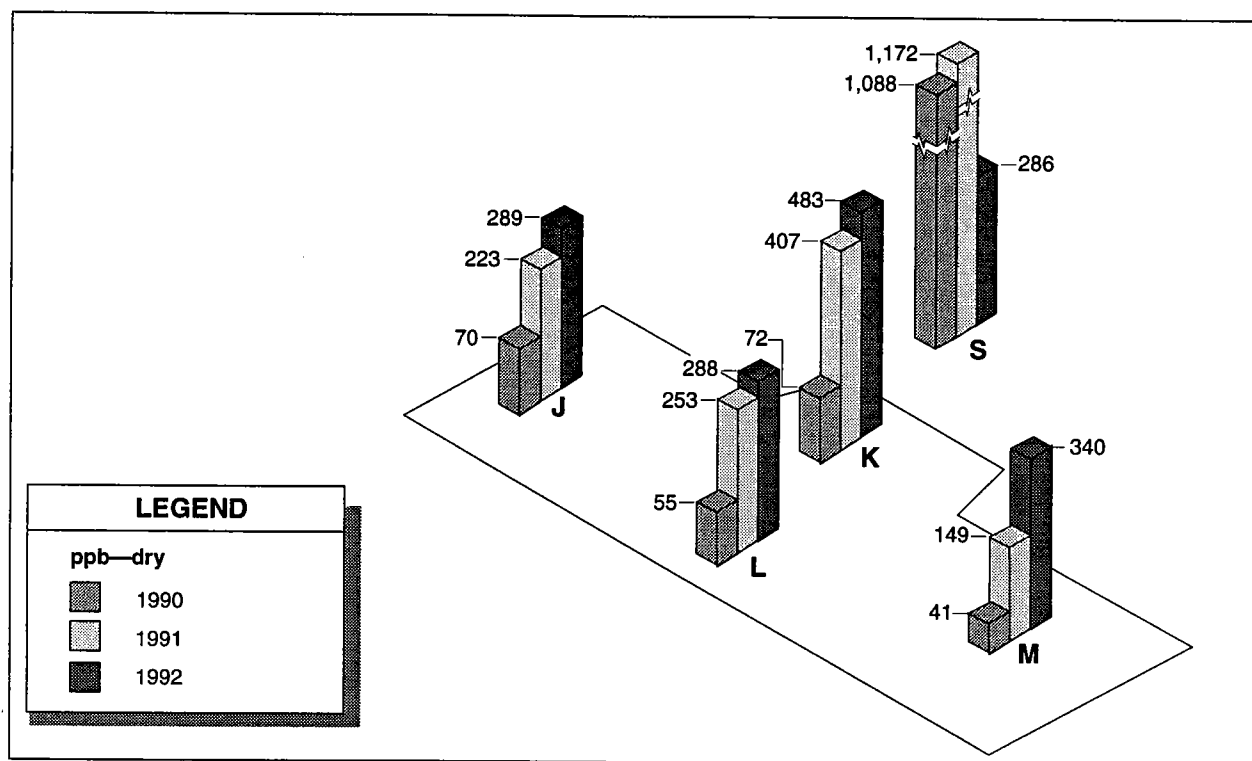


Figure 5-7. 1990, 1991, and 1992 Spatial Concentrations of LPAHs

A high mercury value at M exceeded the CSL. Mercury was 50 percent of the SQS at K and less than 20 percent at J and L. Sliver values ranged from 33 percent of the SQS at K to less than 10 percent at J, K, and L. Arsenic values ranged from 15 percent of the SQS at L and M to less than 10 percent at J.

At K the regular sample had the highest dry-weight concentrations of all on-cap stations for all organic compounds except anthracene and pyrene. Among PAHs detected in both 1991 and 1992, the average increase was 60 ppb (ranging from 6 ppb to 130 ppb). The increases in PAH concentrations at K were generally not as large as for J and M. The LPAH acenaphthene and the compounds benzyl butyl phthalate and Carbazole were detected at Station K but none of the other cap stations. Aroclor 1254 increased to 160 ppb-dry, the highest concentration and the largest increase for a PCB on the cap surface. Benzyl butyl phthalate and three metals (antimony, cadmium, thallium) were the only parameters detected in 1992 that had not been detected before.

1992 Results

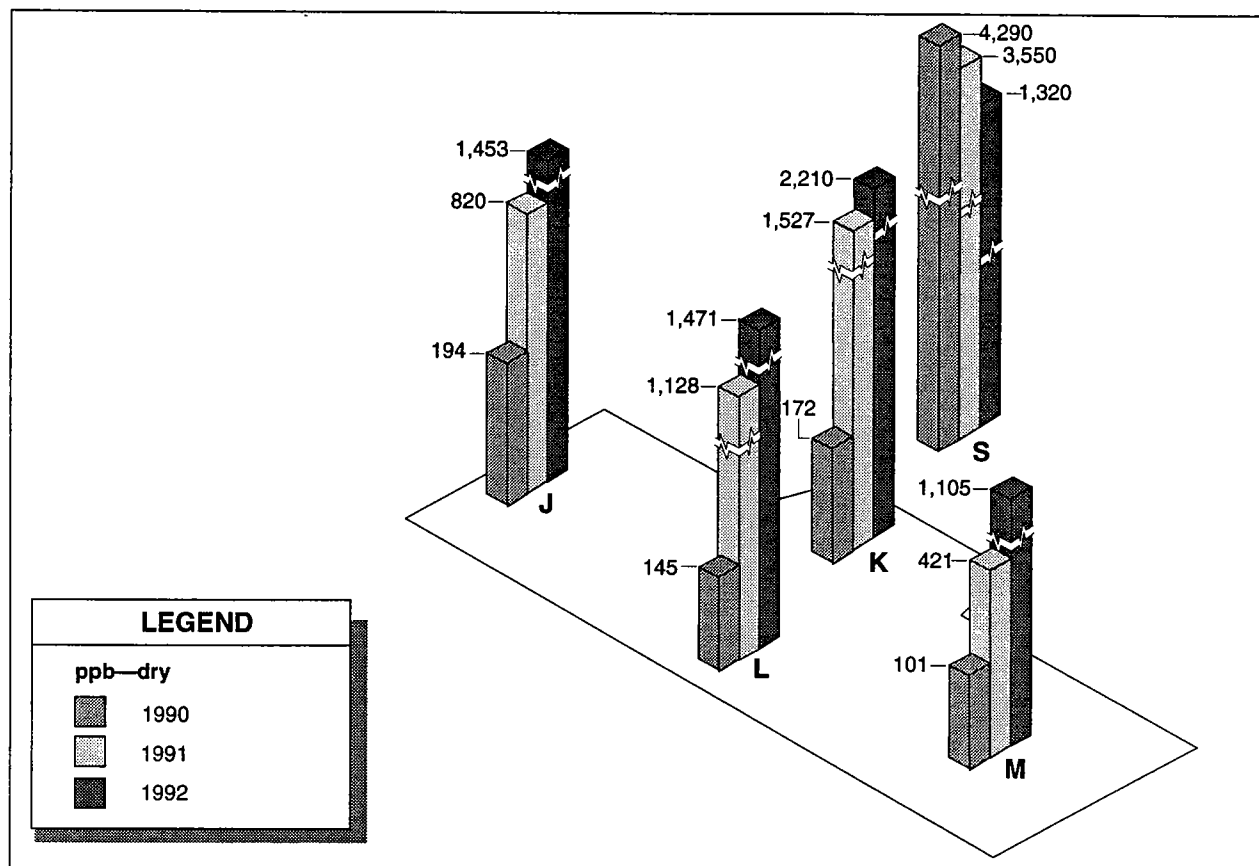


Figure 5-8. 1990, 1991, and 1992 Spatial Concentrations of HPAHs

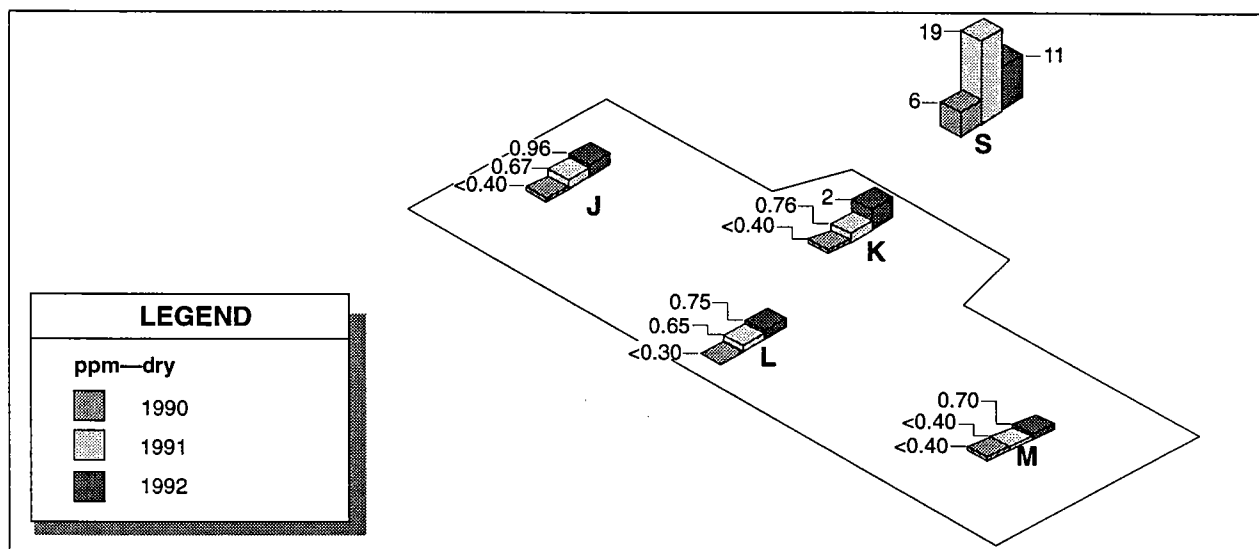


Figure 5-9. 1990, 1991, and 1992 Spatial Concentrations of Silver

TABLE 5-6. Stations J and K: 1992 Comparison to Sediment Standards

Station/Locator	J LTBC20		J2 LTBC20		Sediment Management Standards	
Date Sampled	May 26, 92		Aug 20, 92			
Sample Number	9201091		9201596			
% Solids	68		71			
% TOC	3.2		1.8		SQS Table I	CSL Table III
Parameters	Value	Qual	Value	Qual		
LPAHs (mg/kg OC)						
Naphthalene	1	<MDL	2	<MDL	99	170
Acenaphthene	0.3	<MDL	0.5	<MDL	16	57
Acenaphthylene	0.3	<MDL	0.6	<MDL	66	66
Phenanthrene	4.7		3.5		100	480
Fluorene	0.3	<RDL	0.6	<MDL	23	79
Anthracene	2.2		1.9		220	1,200
2-Methylnaphthalene	1	<MDL	2	<MDL	38	64
Total LPAHs	9.8		11.1		370	780
HPAHs (mg/Kg OC)						
Fluoranthene	7.8		8.3		160	1,200
Pyrene	11		5.5		1,000	1,400
Benzo(a)anthracene	3.8		3.4		110	270
Chrysene	4.7		5.3		110	460
Total benzofluoranthenes	7.2		6.7		230	450
Benzo(a)pyrene	3.1		3.2		99	210
Indeno(1,2,3-Cd)Pyrene	2.9		2	<RDL	34	88
Dibenzo(a,h)anthracene	1	<MDL	2	<MDL	12	33
Benzo(g,h,i)perylene	3.8		1	<MDL	31	78
Total HPAHs	45.3		37.4		960	5,300
Other (mg/kg OC)						
1,2-Dichlorobenzene	0.3	<MDL	0.6	<MDL	2.3	2.3
1,4-Dichlorobenzene	0.3	<MDL,G	0.6	<MDL,G	3.1	9
1,2,4-Trichlorobenzene	0.3	<MDL,G	0.6	<MDL,G	0.81	1.8
Hexachlorobenzene	0.3	<MDL	0.6	<MDL	0.38	2.3
Diethyl Phthalate	0.9	<MDL	1	<MDL	61	110
Dimethyl Phthalate	0.2	<MDL	0.4	<MDL	53	53
Di-N-Butyl Phthalate	0.9	<MDL,B	1	<MDL,B	220	1,700
Benzyl Butyl Phthalate	0.3	<MDL	1.3		4.9	64
Bis(2-Ethylhexyl)Phthalate	18	B	31	B	47	78
Di-N-Octyl Phthalate	0.3	<MDL	0.6	<MDL	58	4,500
Dibenzofuran	0.9	<MDL	1	<MDL	15	58
Hexachlorobutadiene	0.9	<MDL	1	<MDL	3.9	6.2
N-Nitrosodiphenylamine	0.9	<MDL,B	1	<MDL	11	11
Total PCBs	0.9	<MDL	N A		12	65
Other (dry weight µg/kg)						
Phenol	70	<MDL	70	<MDL	420	1,200
2-Methylphenol	30	<MDL	20	<MDL	63	63
4-Methylphenol	30	<MDL	20	<MDL	670	670
2,4-Dimethylphenol	30	<MDL	30	<MDL	29	29
Pentachlorophenol	30	<MDL	20	<MDL,G	360	690
Benzyl Alcohol	30	<MDL	20	<MDL	57	73
Benzoic Acid	70	<MDL	70	<MDL	650	650
Metals (mg/kg dry weight)						
Mercury	0.16		0.07	E	0.41	0.59
Arsenic	4.4	E	13		57	93
Cadmium	0.15	E	0.3	<MDL	5.1	6.7
Chromium	13		13		260	270
Copper	18		15		390	390
Lead	12		23		450	530
Silver	0.96		1.1		6.1	6.1
Zinc	51		49		410	960
NA - Not Available						
Exceeds SQS			Exceeds CSL			

1992 Results

TABLE 5-6 (continued). Stations J and K: 1992

Comparison to Sediment Standards

Section/Locator	K LTBC21		K Rep LTBC21		K2 LTBC21		Sediment Management Standards	
Date Sampled	May 26, 92		May 26, 92		Aug 20, 92			
Sample Number	9201092		9201093		9201595			
% Solids	61		64		68		SQS Table I	CSL Table III
% TOC	2.8		2.7		2			
Parameters	Value	Qual	Value	Qual	Value	Qual		
LPAHs (mg/kg OC)								
Naphthalene	2	<MDL	2	<MDL	2	<MDL	99	170
Acenaphthene	0.4	<RDL	0.4	<RDL	0.5	<RDL	16	57
Acenaphthylene	0.4	<MDL	0.4	<MDL	0.5	<MDL	66	66
Phenanthrene	9.3		8.5		13		100	480
Fluorene	1.2		1.3		2.6		23	79
Anthracene	4.3		5.6		9.5		220	1,200
2-Methylnaphthalene	2	<MDL	2	<MDL	2	<MDL	38	64
Total LPAHs	19.6		20.2		30.1		370	780
HPAHs (mg/kg OC)								
Fluoranthene	15		17		23		160	1,200
Pyrene	12		9.3		18		1,000	1,400
Benzo(a)anthracene	8.2		7		11		110	270
Chrysene	11		10		15		110	460
Total benzofluoranthenes	14.3		14.8		21		230	450
Benzo(a)pyrene	7.5		6.3		8		99	210
Indeno(1,2,3-Cd)Pyrene	4.3		3.3		5		34	88
Dibenzo(a,h)anthracene	2	<MDL	2	<MDL	2	<RDL	12	33
Benzo(g,h,i)perylene	5		3.3		3.6		31	78
Total HPAHs	79.3		73		106.6		960	5,300
Other (mg/kg OC)								
1,2-Dichlorobenzene	0.4	<MDL	0.4	<MDL	0.5	<MDL	2.3	2.3
1,4-Dichlorobenzene	0.4	<MDL,G	0.4	<MDL,G	0.5	<MDL,G	3.1	9
1,2,4-Trichlorobenzene	0.4	<MDL,G	0.4	<MDL,G	0.5	<MDL,G	0.81	1.8
Hexachlorobenzene	0.4	<MDL	0.4	<MDL	0.5	<MDL	0.38	2.3
Diethyl Phthalate	1	<MDL	1	<MDL	2	<MDL	61	110
Dimethyl Phthalate	0.3	<MDL	0.3	<MDL	0.4	<MDL	53	53
Di-N-Butyl Phthalate	1	<MDL,B	1	<MDL,B	2	<MDL,B	220	1,700
Benzyl Butyl Phthalate	1.4		1.3		3.3		4.9	64
Bis(2-Ethylhexyl)Phthalate	36	B	33	B	75	B	47	78
Di-N-Octyl Phthalate	0.4	<MDL	0.4	<MDL	0.5	<MDL	58	4,500
Dibenzofuran	1	<MDL	1	<MDL	2	<MDL	15	58
Hexachlorobutadiene	1	<MDL	1	<MDL	2	<MDL	3.9	6.2
N-Nitrosodiphenylamine	1	<MDL,B	1	<MDL,B	2	<MDL	11	11
Total PCBs	5.7		1	<MDL	NA		12	65
Other (dry weight µg/kg)								
Phenol	80	<MDL	80	<MDL	70	<MDL	420	1,200
2-Methylphenol	30	<MDL	30	<MDL	30	<MDL	63	63
4-Methylphenol	30	<MDL	30	<MDL	30	<MDL	670	670
2,4-Dimethylphenol	30	<MDL	20	<MDL	30	<MDL	29	29
Pentachlorophenol	30	<MDL	30	<MDL	30	<MDL,G	360	690
Benzyl Alcohol	30	<MDL	30	<MDL	30	<MDL	57	73
Benzoic Acid	80	<MDL	80	<MDL	70	<MDL	650	650
Metals (mg/kg dry weight)								
Mercury	0.2		0.16		0.088	E	0.41	0.59
Arsenic	4.9	E	5.7	E	8.8		57	93
Cadmium	0.33	E	0.31	E	0.29		5.1	6.7
Chromium	18		16		13		260	270
Copper	26		20		19		390	390
Lead	13		16		8.7		450	530
Silver	2		1.3		1.3		6.1	6.1
Zinc	66		59		59		410	960
NA - Not Available			Exceeds CSL		Exceeds SQS			

TABLE 5-7. Stations L, M, and S: 1992 Comparison to Sediment Standards

Section/Locator	L LTBC22		M LTBD23		S LTBD25		Sediment Management Standards	
Date Sampled	May 26, 92		May 26, 92		Jul 01, 92			
Sample Number	9201094		9201095		9201379			
% Solids	67		71		75			
% TOC	3.7		1.3		0.47		SQS Table I	CSL Table III
Parameters	Value	Qual	Value	Qual	Value	Qual		
LPAHs (mg/kg OC)								
Naphthalene	1	<MDL	3	<MDL	6	<MDL	99	170
Acenaphthene	0.3	<MDL	0.8	<MDL	2	<MDL	16	57
Acenaphthylene	0.3	<MDL	0.8	<MDL	2	<MDL	66	66
Phenanthrene	3.8		9.2		40		100	480
Fluorene	0.3	<RDL	0.8	<RDL	2	<MDL	23	79
Anthracene	2.1		12		7.9		220	1,200
2-Methylnaphthalene	1	<MDL	3	<MDL	6	<MDL	38	64
Total LPAHs	8.8		29.6		65.9		370	780
HPAHs (mg/kg OC)								
Fluoranthene	7.6		18		77		160	1,200
Pyrene	5.7		12		57		1,000	1,400
Benzo(a)anthracene	3.8		8.5		26		110	270
Chrysene	5.7		13		26		110	460
Total benzo(a)fluoranthenes	7.9		17		76		230	450
Benzo(a)pyrene	3.8		6.8		4	<MDL	99	210
Indeno(1,2,3-Cd)Pyrene	2.3		4.2		4	<MDL	34	88
Dibenzo(a,h)anthracene	1	<MDL	3	<MDL	6	<MDL	12	33
Benzo(g,h,i)perylene	2.1		3.9		4	<MDL	31	78
Total HPAHs	39.9		86.4		280		960	5,300
Other (mg/kg OC)								
1,2-Dichlorobenzene	0.3	<MDL	0.8	<MDL	2	<MDL	2.3	2.3
1,4-Dichlorobenzene	0.3	<MDL,G	0.8	<MDL,G	2	<MDL,G	3.1	9
1,2,4-Trichlorobenzene	0.3	<MDL,G	0.8	<MDL,G	2	<MDL,G	0.81	1.8
Hexachlorobenzene	0.3	<MDL	0.8	<MDL	2	<MDL	0.38	2.3
Diethyl Phthalate	0.8	<MDL	2	<MDL	4	<MDL	61	110
Dimethyl Phthalate	0.2	<MDL	0.5	<MDL	2	<MDL	53	53
Di-N-Butyl Phthalate	0.8	<MDL,B	2	<MDL,B	4	<MDL,B	220	1,700
Benzyl Butyl Phthalate	0.3	<MDL	0.8	<MDL	2	<MDL	4.9	64
Bis(2-Ethylhexyl)Phthalate	12	B	24	B	190		47	78
Di-N-Octyl Phthalate	0.3	<MDL	0.8	<MDL	2	<MDL	58	4,500
Dibenzofuran	0.8	<MDL	2	<MDL	4	<MDL	15	58
Hexachlorobutadiene	0.8	<MDL	2	<MDL	4	<MDL	3.9	6.2
N-Nitrosodiphenylamine	0.8	<MDL,B	2	<MDL,B	4	<MDL	11	11
Total PCBs	3.2		4		9	<RDL	12	65
Other (dry weight µg/kg)								
Phenol	70	<MDL	70	<MDL	70	<MDL	420	1,200
2-Methylphenol	30	<MDL	30	<MDL	20	<MDL	63	63
4-Methylphenol	30	<MDL	30	<MDL	20	<MDL	670	670
2,4-Dimethylphenol	30	<MDL	20	<MDL	30	<MDL	29	29
Pentachlorophenol	30	<MDL	30	<MDL	20	<MDL	360	690
Benzyl Alcohol	30	<MDL	30	<MDL	20	<MDL	57	73
Benzoic Acid	70	<MDL	70	<MDL	70	<MDL	650	650
Metals (mg/kg dry weight)								
Mercury	0.075		0.73		0.71		0.41	0.59
Arsenic	6	E	7	E	5.3		57	93
Cadmium	0.15	E	0.13	E	1.5		5.1	6.7
Chromium	14		12		21	G	260	270
Copper	18		17		130		390	390
Lead	29		11		16		450	530
Silver	0.75		0.7		11		6.1	6.1
Zinc	54		46		170	G	410	960
		Exceeds SQS		Exceeds CSL				

1992 Results

In 1992, in addition to the regular sample, a field replicate was analyzed from K. The field replicate was prepared from three additional grab samples and provides an indication of sampling variability. The routine sample and the field replicate from K shared virtually the same composition. Except for Aroclor 1254, the same compounds and metals were detected in both the regular sample and the field replicate. A simple test of total variability was conducted. The difference in the measured concentrations was calculated for all detected compounds, the range was divided by the mean for that compound, and the result was multiplied by 100, giving a percentage of difference between the two samples. Among detected compounds and metals, the difference between the two samples ranged from 0 percent to 42 percent, with the average difference below 20 percent. These differences show that some sampling variability occurred but that it was within a range seen in previous studies (Metro 1984).

At M, 12 PAHs were detected, six more than in 1991. On average, M showed the largest increases in PAH concentrations. The average increase of PAHs detected in both 1991 and 1992 was 91 ppb, with a range of increases between 72 ppb and 164 ppb. Most importantly, M concentrations became more comparable to J and L, reducing the amount of spatial differentiation that was present in 1991. In 1992, bis(2-ethylhexyl)phthalate, antimony, cadmium, thallium, and silver were among chemicals detected for the first time at M.

At J, PAH concentrations increased between 29 ppb and 220 ppb, averaging 66 ppb. Five PAHs and three metals were detected for the first time at J. Bis(2-ethylhexyl)phthalate reappeared after being undetected in 1991. Aroclor 1254 was not detected, despite being detected at J in 1991 and at the other three stations in 1992, partially because a higher detection limit.

L showed the least amount of change and had 10 PAH compounds detected in 1991 and 12 in 1992. PAH concentrations increased an average of 33 ppb (ranging from 12 ppb to 70 ppb). Perhaps the most noteworthy change was the increase in Aroclor 1254 to 120 ppb.

As in 1991, metals were not highly spatially differentiated. In 1992, the highest concentration on the cap surface for most metals, including all the SMS metals except arsenic, lead, and mercury, was at K. However, the differences between stations were usually minor. Lead mercury and silver were the only metals to change significantly at K and M. At J and L all changes in metals concentrations were minor. The increases at M made concentrations there more comparable to J and L.

In 1992, cadmium, antimony, and thallium were detected on the cap surface for the first time, and they were detected at all four stations. In general these were trace levels and were the result of achieving detection limits lower than those in previous years.

Silver was the only metal to increase at all four stations. The largest increase was at K, where it more than doubled to 2 ppm. At the other three stations the increase was less than 0.3 ppm. Silver was detected for the first time at M, at a concentration (0.7 ppm) comparable to L and J (0.75 ppm and 0.96 ppm, respectively). Mercury increased at three stations, but the increase at M was so large that it may be an anomaly. At M, the concentration increased by a factor of 13 to 0.73 ppm, which is more than three times higher than the concentration at K, the station with the highest concentrations of most priority pollutants.

J and L did not show any other increases in metals concentrations. The 1992 regular sample from K had higher concentrations for beryllium, chromium, copper, lead, nickel, and zinc, in addition to the aforementioned changes for cadmium, mercury, and silver. The changes for beryllium, cadmium, chromium, copper, nickel and zinc were minor (10 to 45 percent higher than the 1991 value). Therefore, lead, mercury, and silver were the only metals to increase appreciably at K. Also, the differences between the 1991 K sample and the 1992 field replicate at K were even smaller.

Three of the four cap samples had higher fractions of sand in 1992 than 1991. J, L, and M had roughly 81 to 84 percent sand and 15 to 20 percent mud (silt + clay) in 1991. In 1992, samples from J and L were composed of 90 percent sand and 10 percent mud. M had 97 percent sand and 3 percent mud. Unlike 1991, in 1992 the station generally regarded as the most contaminated, K, had the highest fraction of fine material among surface samples. The regular sample from K was a composition of 83 percent sand and 17 percent mud, while the field replicate had 88 percent sand and 12 percent mud. Since contaminant concentrations continue to increase despite a change towards coarser material, factors other than the ability of contaminants to sorb to fine materials must account for the increases in concentrations on the cap. The organic carbon content of the sample appears to be involved, but the relationship between higher organic carbon content and higher concentrations is not always maintained.

1992 Results**Specifics of Post-Storm Sampling**

Severe scouring of the contaminated intertidal and nearshore sediments was observed during a storm discharge from the outfall at approximately a zero tide in June 1992. A plume of turbid water was observed moving over the northern half of the cap. Metro chose to collect grab samples at two stations, J and K, in August to see if recontamination of the cap had occurred.

Post-storm samples did not reflect an increase in concentrations because one station experienced varied changes and the other had reduced values. Fewer PAHs and markedly lower PAH concentrations were observed in the post-storm sample from J than from the regular sampling in May. Only 9 PAHs were detected, compared to 12 earlier in the year and 8 in 1991. Detected PAH concentrations were noticeably lower than the earlier sampling, and even slightly lower than the 1991 results. Coprostanol, an indicator of feces, dropped to below detection limits. Benzyl butyl phthalate was detected for the first time at J, and the concentration of bis(2-ethylhexyl)phthalate was essentially the same as the May sampling. The arsenic concentration in the post-storm sample was higher than the in regular sample, but was comparable to the 1991 result. The only other distinguishable change in the post-storm sample was a decrease in the mercury concentration to below the 1991 J value.

Changes at K were less discernible. When compared to the average concentration of the 1992 K and the field replicate samples, the post-storm sample had lower, equivalent, and higher concentrations. Perhaps the most striking changes were the large increases in two phthalates (benzyl butyl phthalate and bis[2-ethylhexyl]phthalate) and the drop in Coprostanol to below detection limits, similar to the findings at J. The LPAHs acenaphthene, fluorene, and anthracene concentrations were higher in the post-storm sample, as were those for the HPAHs fluoranthene, pyrene, and benzo(k)fluoranthene. Chrysene, benzo(b)fluoranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, and benzo(g,h,i)perylene concentrations were lower. Dibenzo (a,h)anthracene was detected on the cap surface for the first time, at a level below the quantification limit. Using only PAHs detected in all three samples, the total LPAH concentration was 15 percent higher in the post-storm sample, while the total HPAH concentration was unchanged. Similar to the findings at J, the arsenic concentration was higher than the regular sampling in May but lower than the results in 1991. Lead was the only other metal to increase. The concentration of several metals decreased, including a drop in mercury to less than the 1991 value.

The particle size distribution did not change substantially. The post-storm sample at J was 89 percent sand and 11 percent mud, a change of only 1 percent toward the finer fraction. The K sample was 88 percent sand and 12 percent mud, virtually identical to the field replicate at K, which had more of the coarse fraction than the regular sample (83 percent sand, 17 percent mud). The organic carbon content of both post-storm samples was noticeably lower than the earlier 1992 samples yet still higher than samples from 1990 and 1991.

When post-storm values were compared to the TOC-normalized criteria, one detected compound exceeded the SMS. At K, bis(2-ethylhexyl)phthalate was 75 ppm organic carbon normalized and about twice the earlier 1992 values of 33 and 36 ppm organic carbon normalized, which were below the SQS values of 47 ppm organic carbon normalized. Two factors that contributed to the higher post-storm value were a 50 percent increase in dry-weight chemical concentrations and a 30 percent decrease in TOC. Bis(2-ethylhexyl)phthalate has been a ubiquitous compound in past sediment studies and will be a consideration for source control.

1992 Chemicals Present at S

In the 1992 sample collected at S, the number of compounds detected and most concentrations dropped, often to less than one-half the 1991 values. Organic compound concentrations were similar to those found on the cap surface. Fluoranthene was the only compound that remained unchanged from 1991. The LPAHs acenaphthene and fluorene and the HPAHs, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, and benzo(g,h,i)perylene were undetected in 1992 despite being measured in sufficient quantities in 1990 and 1991. Dibenzo(a,h)anthracene was not detected either. The PAHs that were detected in 1992 (except fluoranthene) had concentrations of less than half the 1991 concentrations. Benzyl butyl phthalate and dibenzofuran were not detected although both had been present in 1990 and 1991 at S. The 1992 bis(2-ethylhexyl)phthalate concentration was roughly one-half the 1991 concentration. Aroclor 1254 concentrations were 20 percent lower than 1991 values. There is no obvious explanation for this apparent drop in values, but it may be the result of field sampling variability and heterogeneity at the station.

Most 1992 metals concentrations were lower than the 1991 concentrations, but the drops were not as substantial as those for organic compounds. Cadmium and mercury were the only metals to be higher in 1992 than 1991. Compared to the cap surface stations in 1992, aluminum, antimony, arsenic, beryllium, chromium, iron, manganese, and nickel concentrations at S were below, within,

1992 Results

or slightly above the respective ranges evident on the cap. Among the SMS metals, cadmium, copper, lead, mercury, silver, and zinc concentrations at S were still high compared to the cap surface. Mercury and silver concentrations were above the CSL.

The particle size distribution at S has not changed over the 3 years. The sand fraction has always been 96 percent of the sample and the total of the finer fractions (silt and clay) has varied between 4 percent and 8 percent. The TOC value in 1992 was less than one-third the 1991 value and even lower than the 1990 value. Based on this limited data set, it appears that a low TOC value is more typical of these sandy intertidal sediments.

SECTION 6

BENTHIC RECOLONIZATION

The monitoring plan for the Denny Way sediment cap calls for studies of the cap recolonization by benthic organisms at the project site. The primary method used to evaluate benthic recolonization was to obtain taxonomy data from surface sediment samples. Benthic taxonomy studies are to be conducted at yearly intervals for 3 years and then again at five years. Studies after 5 years are to be determined by regulatory agencies. The first 3 years of studies (1990, 1991, and 1992) have been completed.

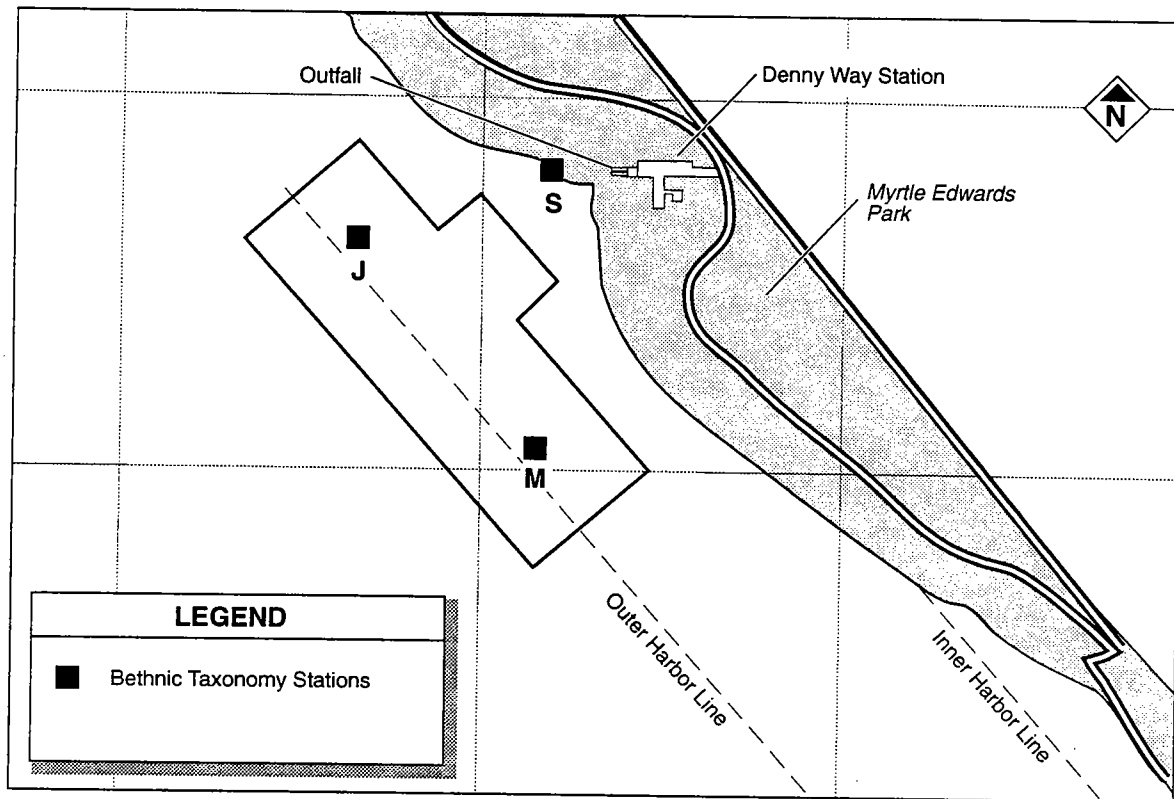
This section describes the three studies and compares the change in the number and types of benthic organisms over 3 years. Complete benthic taxonomy data appear in Appendix H. Also discussed in this section are the sediment-profile camera survey and the video camera survey. The sediment-profile survey had two primary focuses: the first was to document the nature of the benthic communities and the second was to determine the aerial extent and uniformity of capping material across the project site. This section discusses the survey's documentation of the benthic communities. Methods are described in Section 3 and the entire report appears in Appendix D. The video camera survey gathered information over a large area about the cap and cap biology.

SURFACE SEDIMENT SAMPLES

In August 1990, 1991, and 1992, a Metro research team collected sediment samples at two on-cap stations and one intertidal station as prescribed by the monitoring plan. The two on-cap stations provide spatial coverage on the cap, with Station J in the northern section and Station M in the southern section (see Map 6-1).

Method

The sampling team collected the on-cap benthic taxonomy samples at Stations J and M with a 0.1-square-meter Van Veen grab sampler that they operated from the *RV Liberty*. Once the samples were on board, the sea water was drained and sample thickness was measured to ensure a depth penetration of 10 centimeters. A team member washed each sample through a 1-millimeter mesh screen with water from a hose. Everything that did not wash through the screen was put into a jar



Map 6-1. Benthic Taxonomy Stations

and labeled by station and replicate number. The team took five samples per station. The screened samples were preserved in buffered formalin and later transferred to alcohol. Taxonomic analysis was conducted by Marine Taxonomic Services.

Researchers collected samples at the intertidal station, Station S, from the beach at low tide during 1990, 1991, and 1993. Samples were collected by inserting a 2-inch-diameter stainless-steel coring tube into the sediment to a depth of 6 to 8 inches. For 1990, six replicate samples composed of one core each were taken and placed into glass jars. For 1991 six replicate samples composed of two cores each were taken and placed into glass jars. The samples were screened and treated the same as the intertidal samples. Analysis was conducted by Marine Taxonomic Services.

Because of their much smaller size, the intertidal sample results cannot be compared quantitatively to the subtidal samples, but they can be compared qualitatively for the types of species present. Also, because of the difference in number of cores per sample, the 1990 intertidal results are not directly compared to the 1991 intertidal results.

Recolonization Stages

The progress of benthic recolonization of an area can be described by the types of organisms that move into a recently disturbed environment. The first invertebrates to re-populate an area are relatively short-lived and have relatively low biomass. They are filter feeders or surface deposit feeders and do not live in the substrate. These organisms add organic material to the bottom sediment, allowing the next stage of organisms to gain a foothold in the area.

The next type of organisms to move into a recently disturbed area are deposit feeders. They feed on deposits of organic material on or just below the bottom surface and are less mobile than initial recruits, but they are able to take advantage of feeding opportunities over a larger area than other types of organisms. These infaunal deposit feeders continue to contribute organic material in and on the bottom sediments. By penetrating the substrate, they aerate the sediments, allowing the next stage of bottom feeders to inhabit the area. These deposit feeders are the first organisms to begin living in the bottom sediments.

The last type of benthic organisms to move into an area are completely dependent on organic material in the bottom sediments for nourishment. These organisms typically burrow into the sediment and feed at depth, head down. These organisms are the least mobile and are most likely to be found in a relatively undisturbed environment.

1990 Results

The 1990 benthic taxonomy study showed that recolonization was beginning, with 138 total species counted in the samples from the cap. Numbers of individuals and biomass were low, as expected, after only 5 months. Polychaetes were the most abundant, and had the greatest number of species and the highest biomass weight of any taxonomic group found on the sediment cap. The most abundant organisms were the polychaetes, *Aphelochaeta multifilis*, *Capitella capitata* complex, *Heteromastus filobranchus*, and *Prionospio steenstrupi*; the mollusks *Alvania compacta*, *Bivalvia juv.* and *Macoma juv.*; and the crustacean *Euphilomedes*

Surface Sediment Samples

carcharodonta. The most abundant organism was *Macoma sp. Juv.* which averaged 171 individuals at Station M and 115 individuals at Station J (see Tables 6-1 and 6-2).

The benthic community was made up of near-surface deposit and filter feeders, which are expected to be the first to recolonize a recently disturbed area. Bivalves and crustaceans were rare, with the exception of *Macoma* and the ostracod *Euphilomedes carcharodonta*. Since the *Macoma* bivalves observed on the cap were juveniles and no adults were found, the bivalves likely settled onto the cap from a spawn set from the surrounding areas and developed for 4 or 5 months until they were sampled. *Macoma* is a surface deposit feeder living in near-surface sediments and is more likely to move into an area after it has been colonized by organisms living on the sediments. *E. carcharodonta* is predominantly an epifaunal organism, inhabiting debris and structures at or above the bottom sediments, and is likely to be among the first to recolonize the cap.

TABLE 6-1. Representative Species at Station M, 1990

Taxon	Number of Individuals Per 0.1 m ²					Avg Rep
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	
Polychaetes						
<i>Aphelocheata multifilis</i>	21	23	27	20	19	22
<i>Armandia brevis</i>	0	0	1	0	0	0.2
<i>Capitella capitata complex</i>	26	18	19	11	7	16.2
<i>Cautleriella alata</i>	0	0	0	0	1	0.2
<i>Eteone longa</i>	4	6	11	10	3	6.8
<i>Exogone lourei</i>	0	2	1	0	0	0.6
<i>Heteromastus filobranchus</i>	4	8	0	12	4	5.6
<i>Lumbrineris californiensis</i>	1	3	4	2	2	2.4
<i>Lumbrineris sp. Indet.</i>	1	2	6	1	3	2.6
<i>Pectinaria californiensis</i>	8	2	0	2	0	2.4
<i>Pectinaria granulata</i>	5	11	8	8	5	7.4
<i>Prionospio steenstrupi</i>	10	21	21	30	13	19
<i>Spiochaetopterus costarum</i>	7	7	0	4	7	5
Mollusks						
<i>Alvania compacta</i>	96	8	4	3	1	22.4
<i>Axinopsida serricata</i>	2	2	4	1	16	5
<i>Bivalvia sp. Juv.</i>	21	18	29	26	4	19.6
<i>Macoma sp. Juv.</i>	96	233	183	167	177	171
Crustaceans						
<i>Euphilomedes carcharodonta</i>	5	16	24	16	9	14
<i>Leptochelia savignyi</i>						

TABLE 6-2. Representative Species at Station J, 1990

Taxon	Number of Individuals Per 0.1 m ²					
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Avg Rep
Polychaetes						
<i>Aphelochaeta multifilis</i>	35		1	27	4	16.75
<i>Capitella capitata</i> complex	20		24	9	6	14.75
<i>Glycera capitata</i>	4		4	11	4	5.75
<i>Heteromastus filobranthus</i>	20		5	7	9	10.25
<i>Lumbrineris luti</i>						0
<i>Lumbrineris</i> sp. Indet.	3		0	1	0	1
<i>Nephtys cornuta franciscanum</i>	6		1	2	3	3
<i>Pectinaria californiensis</i>	3		3	5	3	3.5
<i>Pectinaria granulata</i>	2		2	2	2	2
<i>Polycirrus</i> sp. complex	11		1	12	4	7
<i>Prionospio steenstrupi</i>	19		2	3	5	7.25
<i>Scoletoma luti</i>						0
<i>Spiochaetopterus costarum</i>	7		7	8	6	7
Mollusks						
<i>Alvania compacta</i>	19		21	7	271	79.5
<i>Axinopsida serricata</i>	0		0	2	7	2.25
<i>Bivalvia</i> sp. Juv.	40		0	19	2	15.25
<i>Macoma</i> sp. Juv.	130		49	201	82	115.5
Crustaceans						
<i>Euphilomedes carcharodonta</i>	17		4	21	5	11.75
<i>Leptochelia savignyi</i>						0

The most numerically dominant polychaetes were the Cirratulid, *Aphelochaeta multifilis*; the Capitellids, *Capitella capitata* complex and *Heteromastus filobranthus*; and the Spionid, *Prionospio steenstrupi*. Cirratulids, Spionids and Capitellids are known early colonizers of disturbed environments. Spionids are tube-dwelling deposit feeders. *Capitella capitata* is a near-surface feeder that is well equipped to colonize stressed habitats that are unsuitable for other species. The polychaetes *Pectinaria californiensis* and *Pectinaria granulata* were also present on the cap. They are head-down deposit feeders that represent species that are usually last in the recolonization sequence.

Abundance. Abundance was determined by averaging five replicates at each station. Because the second replicate sample for Station J in 1990 was destroyed during transit to the analytical laboratory, the remaining four replicate samples were averaged for this station.

Large numbers of *Macoma* sp. juv. made mollusks the most numerically abundant taxonomic group, averaging 243 at Station M and 222 at Station J. This compares to an average of 195 polychaetes at Station M and 128 at Station J. Both Station M and J averaged 23 crustaceans.

Surface Sediment Samples

Number of Species. Polychaetes had the highest number of species of any taxonomic group on the cap. They were represented by 68 species at Station M and 50 species at Station J. This compares to 28 species of mollusks at Station M and 17 species at Station J. There were 18 species of crustaceans at Station M and 21 species at Station J.

Biomass. Five replicate sample weights were averaged at each station. Even though mollusks were greater in number, most were juvenile *Macoma*, so that polychaetes had the highest biomass weight. At Station J, polychaetes weighed an average of 1.37 grams, compared to 0.35 grams for mollusks and 0.14 grams for crustaceans. At Station M, polychaetes weighed an average of 1.99 grams per sample replicate, while mollusks weighed 0.44 grams and crustaceans weighed 0.25 grams.

Productivity. Productivity was determined by comparing abundance, number of species, and biomass for each station. Station M was slightly more productive than Station J in all areas. There were 117 different species counted at Station M compared to 92 species at Station J. Station M averaged 470 individuals per replicate sample compared to an average of 378 at Station J. Biomass weight average was 2.7 grams at Station M compared to 1.9 grams at Station J.

Station S. There were four species represented in the five replicate samples at Station S in 1990 (see Table 6-3). One high replicate made *Cirripidea sp. Indet.* the most numerically abundant with 52 individuals. The next most abundant species was *Capitella capitata complex* with 44 individuals. The other two species were *Oligochaeta sp. Indet.* with four total individuals and *Eteone longa* with three.

TABLE 6-3. Species at Station S, 1990						
Taxon	Number of Individuals per 0.1 m ²					Totals
	Rep A	Rep B	Rep C	Rep D	Rep E	
Polychaetes						
<i>Capitella capitata complex</i>	10	14	6	10	4	44
<i>Eteone longa</i>	1		2			3
<i>Oligochaeta sp. Indet.</i>	3			1		4
Crustaceans						
<i>Cirripidea sp. Indet.</i>	3			2	47	52
Total Individuals	17	14	8	13	51	103

1991 Results

The 1991 benthic taxonomy study showed that abundance, number of species, and biomass increased in 12 months. While the benthic community was still largely made up of species likely to be the first to inhabit the cap, it is beginning to progress toward a community typically found in a more stable environment. The most abundant organisms by replicate average were, in order, the crustacean *Euphilomedes carcharodonta*, and the polychaetes, *Aphelochoaeta multifilis*, *Lumbrineris* sp. Indet, *Capitella capitata* complex, and *Prionospio steenstrupi*. *Axinopsida serricata* was the only mollusk in the top ten most abundant at both Stations J and M. *Macoma* sp. Juv. was the eighth most abundant at station M (see Tables 6-4 and 6-5).

TABLE 6-4. Representative Species at Station J, 1991

TABLE 6-4. Representative Species at Station J, 1991											
Taxon	Number of Individuals Per 0.1 m ²										Avg Rep 1991
	1990					1991					
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	
Polychaetes											
<i>Aphelochoeta multifilis</i>	35		1	27	4	117	33	22	26	28	45.2
<i>Capitella capitata</i> complex	20		24	9	6	180	44	4	23	28	55.8
<i>Glycera capitata</i>	4		4	11	4	23	15	4	3	10	11
<i>Heteromastus filobranchus</i>	20		5	7	9	68	28	19	9	14	27.6
<i>Lumbrineris luti</i>						18	17	12	12	23	16.4
<i>Lumbrineris</i> sp. Indet.	3			1		101	45	25	25	25	44.2
<i>Nephtys cornuta franciscanum</i>	6		1	2	3	24	14	1	1	9	9.8
<i>Pectinaria californiensis</i>	3		3	5	3	15	15	3	6	14	10.6
<i>Pectinaria granulata</i>	2		2	2	2	3	2	4	0	4	2.6
<i>Polycirrus</i> sp. complex	11		1	12	4	11	9	17	15	14	13.2
<i>Prionospio steenstrupi</i>	19		2	3	5	70	40	15	24	42	38.2
<i>Scoletoma luti</i>											
<i>Spiochaetopterus costarum</i>	7		7	8	6	7	8	6	5	7	6.6
Mollusks											
<i>Alvania compacta</i>	19		21	7	271	2	1	0	0	0	0.6
<i>Axinopsida serricata</i>				2	7	66	29	25	20	10	30
<i>Bivalvia</i> sp. Juv.	40			19	2	16	0	0	0	1	3.4
<i>Macoma</i> sp. Juv.	130		49	201	82	12	7	4	3	6	6.4
Crustaceans											
<i>Euphilomedes carcharodonta</i>	17		4	21	5	114	65	54	47	50	66
<i>Leptochelia savignyi</i>											

Surface Sediment Samples

TABLE 6-5. Representative Species at Station M, 1991

TABLE 6-5. Representative Species at Station M, 1991											
Taxon	Number of Individuals Per 0.1 m ²										Avg Rep 1991
	1990					1991					
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	
Polychaetes											
<i>Aphelochaeta multifilis</i>	21	23	27	20	19	28	34	67	60	74	52.6
<i>Armandia brevis</i>			1			15	24	10	12	13	14.8
<i>Capitella capitata</i> complex	26	18	19	11	7	25	31	44	53	57	42
<i>Cautleriella alata</i>					1	6	9	5	15	30	13
<i>Eteone longa</i>	4	6	11	10	3	6	3	8	10	5	6.4
<i>Exogone lourei</i>		2	1			6	11	4	11	10	8.4
<i>Heteromastus filobranchus</i>	4	8		12	4	24	13	36	13	44	26
<i>Lumbrineris californiensis</i>	1	3	4	2	2	26	8	6	9	16	13
<i>Lumbrineris</i> sp. Indet.	1	2	6	1	3	60	57	35	57	71	56
<i>Pectinaria californiensis</i>	8	2		2		5	11	3	6	4	5.8
<i>Pectinaria granulata</i>	5	11	8	8	5	11	14	7	14	6	10.4
<i>Prionospio steenstrupi</i>	10	21	21	30	13	23	29	32	25	20	25.8
<i>Spiochaetopterus costarum</i>	7	7		4	7	11	9	11	16	17	12.8
Mollusks											
<i>Alvania compacta</i>	96	8	4	3	1	6	0	1	1	0	1.6
<i>Axinopsida serricata</i>	2	2	4	1	16	21	19	16	25	11	18.4
<i>Bivalvia</i> sp. Juv.	21	18	29	26	4	2	0	1	0	1	0.8
<i>Macoma</i> sp. Juv.	96	233	183	167	177	5	8	73	9	4	19.8
Crustaceans											
<i>Euphilomedes carcharodonta</i>	5	16	24	16	9	100	155	74	138	47	103
<i>Leptochelia savignyi</i>											

The polychaetes *Pectinaria californiensis* and *Pectinaria granulata*, which are indicators of a lower disturbance environment, increased in numbers during 1991. By average number of individuals per replicate sample, *P. californiensis* increased from an average of 2 individuals in 1990 to 6 individuals in 1991 at Station M. *P. californiensis* also increased from 4 individuals to 11 at Station J. *P. granulata* increased from 7 individuals to 10 at Station M and from 2 individuals to 3 at Station J. Also, the polychaete families *Maldanidae* and *Ampharetidae*, which are associated with an established benthic community, were present in small numbers in 1991 while absent in 1990. Crustaceans also increased in abundance. The average replicate sample for crustaceans rose from 23 at Station M in 1990 to an average of 158 per replicate sample in 1991. At Station J the replicate average increased from 23 in 1990 to 90 in 1991.

Number of Species. The total number of species increased to 159 during the first year after cap placement. Polychaete species increased from 50 in 1990 to 68 in 1991 at Station J. The increase was much less at Station M, where polychaetes increased from 68 species to 71 in 1991. The number of mollusk species increased from 17 to 24 at Station J and from 28 to 29 at Station M. Crustacean species increased from 21 to 26 at Station J and from 18 to 26 at Station M.

Abundance. Polychaetes were the most abundant taxonomic group on the cap in 1991. There was an average of 395 individual polychaetes per replicate sample at Station M compared to an average of 158 crustaceans and 73 mollusks. At Station J, polychaetes averaged 364 per sample, while crustaceans averaged 90 and mollusks averaged 64.

Mollusks appeared to decrease in abundance, dropping from an average of 243 individuals per sample in 1990 to 73 in 1991 at Station M. They also dropped at Station J from an average of 222 individuals per sample in 1990 to 64 individuals in 1991. However, biomass increased for mollusks during the same time. At Station M in 1990 mollusks averaged 0.43 grams per sample compared to 1.26 grams per sample in 1991. Mollusk biomass rose at Station J, increasing from 0.35 grams per sample in 1990 to 1.14 grams per sample in 1991. Also, the number of mollusk species increased from 17 in 1990 to 24 in 1991 at Station J, and they increased by 1 at Station M, from 28 in 1990 to 29 in 1991.

The apparent decrease in mollusks can be traced to *Macoma* and *Alvania compacta*. The juvenile bivalve *Macoma* was found in large numbers in 1990. Because there were no adult *Macoma* counted on the cap in 1990, it is likely that the juveniles were the result of a spawn set settling onto the cap from the surrounding areas. The fluctuation of *Macoma* suggests that the population is reaching equilibrium. *Alvania compacta* appeared in large numbers in one replicate sample at each station. Factoring out the high replicate sample of *A. compacta* and the large number of juvenile *Macoma* shows that the mollusk population is increasing steadily in abundance, number of species, and biomass.

Biomass. Polychaetes were the most dominant in terms of biomass again in 1991. They averaged 3.4 grams per replicate sample at Station M and 2.7 grams per sample at Station J. Because of one large replicate sample, crustaceans averaged 2 grams per replicate sample at Station M, while they averaged 0.18 grams at Station J. Removing the high replicate sample, crustaceans averaged 0.65 grams for the remaining samples at Station M. Mollusks averaged 1.26 grams per sample at Station M and 1.14 grams at Station J.

Surface Sediment Samples

Productivity. Station M was slightly more productive than Station J again in 1991. There were 131 different species counted at Station M compared to 121 counted at Station J. The average total abundance for individual organisms was 630 at Station M, compared with 524 at Station J. Biomass weight average was 6.6 grams at Station M, compared to 4 grams at Station J.

Station S. For the intertidal station in 1991, two of the six sample jars were broken, leaving four samples for analysis. There were 15 species and 170 individuals counted in the samples (see Table 6-6). *Anisogammarus pugettensis* was the most numerically abundant at 68 individuals, followed by *Cirripedia sp. Indet* with 61 individuals.

TABLE 6-6. Species at Station S, 1991

Organisms per 0.1 m ²							
Taxon	*Rep 1	Rep 2	Rep 3	Rep 4	*Rep 5	Rep 6	Totals
Polychaetes							
<i>Capitella capitata</i> complex		6	1	11		1	19
<i>Eteone sp. Juv.</i>		1					1
<i>Ophelina acuminata</i>				1			1
<i>Ophelina breviata</i>			1				1
<i>Platynereis bicanaliculata</i>		3	1				4
<i>Spio filicornis</i>		1		1			2
Mollusks							
<i>Bivalvia sp. Juv.</i>				1			1
<i>Mysella tumida</i>				1			1
Crustaceans							
<i>Amphipoda sp. Indet.</i>			4			2	6
<i>Anisogammarus pugettensis</i>		15	49	1		3	68
<i>Aoroides sp. Indet.</i>		1					1
<i>Cancer sp. Indet.</i>			1				1
<i>Cirripedia sp. Indet.</i>		53	8				61
<i>Gnorimosphaeroma oregonensis</i>			1	1			2
<i>Synchelidium rectipalium</i>			1				1
Total Individuals		80	67	17		6	170

* Samples broken prior to shipment.

1992 Results

The 1992 benthic taxonomy study showed that organism abundance and biomass increased. Crustaceans and mollusks are increasing in numbers and biomass. Polychaetes, however, are still the most numerically abundant, and have the greatest number of species and the highest biomass weight. The most abundant species by replicate average are, in order the crustacean *Euphilomedes carcarodonta*, the mollusk *Axinopsida serricata*, the crustacean *Leptocheilia savignyi*, the polychaetes *Prionospio steenstrupi*, *Lumbrineris sp. Indet.*, *Spiochaetopterus costarum*, and the mollusk *Macoma sp. Juv* (see Tables 6-7 and 6-8).

Most of the top seven most abundant species showed a steady increase in numbers over the 3 years of study. The averages for Stations J and M were as follows: *E. carcarodonta* increased from 13 individuals in 1990 to 85 individuals in 1991 and to 191 individuals in 1992; *A. serricata* increased from 4 individuals in 1990 to 24 in 1991 and 191 in 1992; *L. savignyi* increased from no individuals in 1990 or 1991 to 91 individuals in 1992; *P. steenstrupi* increased from 13 individuals in 1990 to 32 individuals in 1991 and 80 individuals in 1992.

Lumbrineris sp. Indet decreased in average abundance by 30 percent in 1992. Averaging both stations, *Lumbrineris* increased from 2 individuals in 1990 to 50 individuals in 1991 and then decreased to 35 individuals in 1992. For the two-station average, *S. costarum* showed steady increase from 6 individuals in 1990 to 9 individuals in 1991 to 22 individuals in 1992. *Macoma sp. Juv.* was the seventh most abundant organism on the cap in 1992, rebounding from low numbers in 1991. The two-station average showed that *Macoma* decreased from 143 individuals in 1990 to 13 individuals in 1991, but then increased to 23 individuals in 1992.

Number of Species. The 1992 study showed the increase in the number of species to be leveling off (see Figure 6-1). There were 132 species counted at Station M and 112 at Station J. The progression of species at Station M increased from 117 in 1990 to 131 in 1991 and then to 132 species in 1992. At Station J the number of species increased from 92 in 1990 to 121 in 1991, then decreased to 112 in 1992.

As in 1990 and 1991, there were more species of polychaetes in 1992, with 75 species at Station M and 65 species at Station J. Mollusks were the next most diverse group in 1992, with 29 species at Station M and 24 species at Station J. There were 23 crustacean species counted at Station M and 18 species at Station J.

Surface Sediment Samples

TABLE 6-7. Representative Species at Station M, 1992

TABLE 6-7. Representative Species at Station M, 1992																	
Taxon	Number of Individuals Per 0.1 m ²																
	1990					1991					1992					Avg Rep 1992	
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
Polychaetes																	
<i>Aphelochaeta multifilis</i>	21	23	27	20	19	28	34	67	60	74	0	0	2	1	3	1.2	
<i>Armandia brevis</i>			1			15	24	10	12	13	7	0	1	1	2	2.2	
<i>Capitella capitata</i> complex	26	18	19	11	7	25	31	44	53	57	0	1	1	4	8	2.8	
<i>Caulleriella alata</i>					1	6	9	5	15	30	1	1	3	2	1	1.6	
<i>Eteone longa</i>	4	6	11	10	3	6	3	8	10	5	1	0	4	0	1	1.2	
<i>Exogone lourei</i>		2	1			6	11	4	11	10	3	11	18	14	42	17.6	
<i>Heteromastus filobranchus</i>	4	8		12	4	24	13	36	13	44	5	0	1	0	1	1.4	
<i>Lumbrineris californiensis</i>	1	3	4	2	2	26	8	6	9	16	0	6	17	12	38	14.6	
<i>Lumbrineris</i> sp. Indet.	1	2	6	1	3	60	57	35	57	71	44	24	26	24	66	36.8	
<i>Pectinaria californiensis</i>	8	2		2		5	11	3	6	4	2	17	34	18	25	19.2	
<i>Pectinaria granulata</i>	5	11	8	8	5	11	14	7	14	6	18	21	14	15	20	17.6	
<i>Prionospio steenstrupi</i>	10	21	21	30	13	23	29	32	25	20	67	75	114	70	112	87.6	
<i>Spiochaetopterus costarum</i>	7	7		4	7	11	9	11	16	17	39	27	34	35	31	33.2	
Mollusks																	
<i>Alvania compacta</i>	96	8	4	3	1	6		1	1		8	0	0	0	1	1.8	
<i>Axinopsida serricata</i>	2	2	4	1	16	21	19	16	25	11	71	77	153	58	95	90.8	
<i>Bivalvia</i> sp. Juv.	21	18	29	26	4	2		1		1							
<i>Macoma</i> sp. Juv.	96	233	183	167	177	5	8	73	9	4	31	22	33	23	5	22.8	
Crustaceans																	
<i>Euphilomedes carcharodonta</i>	5	16	24	16	9	100	155	74	138	47	102	292	399	294	273	272	
<i>Leptochelia savignyi</i>						42					42	49	87	31	150	71.8	

TABLE 6-8. Representative Species at Station J, 1992

Taxon	Number of Individuals Per 0.1 m ²																
	1990					1991					1992					Avg Rep 1992	
	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5		
Polychaetes																	
<i>Aphelochaeta multifilis</i>	35		1	27	4	117	33	22	26	28	1	2	2	1	5	2.2	
<i>Capitella capitata</i> complex	20		24	9	6	180	44	4	23	28	18	23	4	4	50	19.8	
<i>Glycera capitata</i>	4		4	11	4	23	15	4	3	10	13	9	5	1	8	7.2	
<i>Heteromastus filobranchus</i>	20		5	7	9	68	28	19	9	14	0	6	0	2	16	4.8	
<i>Lumbrineris luti</i>						18	17	12	12	23							
<i>Lumbrineris</i> sp. Indet.	3			1		101	45	25	25	25	94	12	10	23	19	31.6	
<i>Nephtys cornuta franciscanum</i>	6		1	2	3	24	14	1	1	9							
<i>Pectinaria californiensis</i>	3		3	5	3	15	15	3	6	14	12	21	8	6	1	9.6	
<i>Pectinaria granulata</i>	2		2	2	2	3	2	4		4	18	4	5	1	17	9	
<i>Polycirrus</i> sp. complex	11		1	12	4	11	9	17	15	14	0	3	2	3	0	1.6	
<i>Prionospio steenstrupi</i>	19		2	3	5	70	40	15	24	42	86	94	36	62	76	70.8	
<i>Scoletoma luti</i>											18	24	35	19	33	25.8	
<i>Spiochaetopterus costarum</i>	7		7	8	6	7	8	6	5	7	11	12	15	8	13	11.8	
Mollusks																	
<i>Alvania compacta</i>	19		21	7	271	2	1				0	0	0	1	0	0.2	
<i>Axinopsida serricata</i>				2	7	66	29	25	20	10	144	95	71	76	69	91	
<i>Bivalvia</i> sp. Juv.	40			19	2	16				1							
<i>Macoma</i> sp. Juv.	130		49	201	82	12	7	4	3	6	35	34	10	18	19	23.2	
Crustaceans																	
<i>Euphilomedes carcharodonta</i>	17		4	21	5	114	65	54	47	50	232	233	282	231	153	226.2	
<i>Leptochelia savignyi</i>						239	231	12	5	62						109.8	

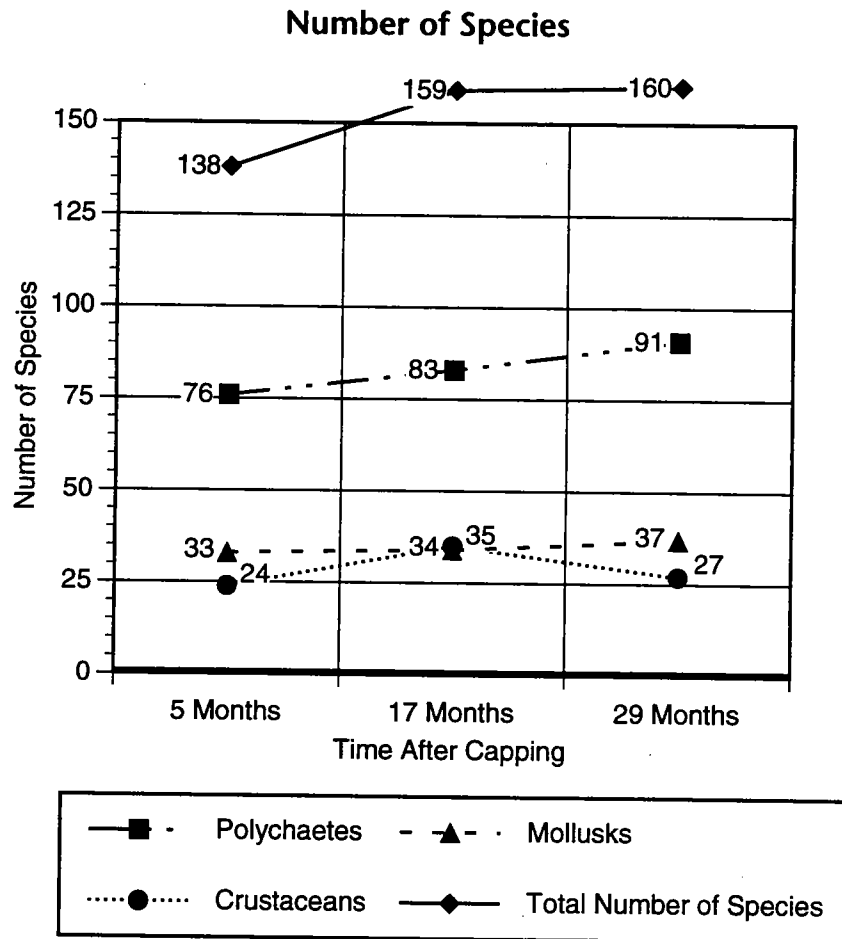


Figure 6-1. Three-Year Trend for Number of Species

Polychaete species showed a steady progression, increasing from 68 species in 1990 to 71 species in 1991 and then to 75 species at Station M. At Station J, polychaetes increased from 50 species in 1990 to 68 species in 1991 and then decreased to 65 species in 1992.

Mollusk species have shown little or no increase over the 3 years, beginning in 1990 with 28 species, then increasing to 29 species for 1991 and 1992 at Station M. At Station J, mollusks increased from 17 species in 1990 to 24 species in 1991 and remained at 24 species in 1992.

Crustacean species varied over the 3 years, increasing from 18 species in 1990 to 26 species in 1991, then decreasing to 23 species in 1992 at Station M. Station J showed crustaceans increasing from 21 species in 1990 to 26 species in 1991 and then decreasing to 18 species in 1992.

Abundance. Crustaceans became the most abundant taxonomic group on the cap in 1992 (see Figure 6-2). They averaged 365 individuals per replicate sample at Station M and 354 individuals at Station J. Polychaetes were the next most abundant, with 341 individuals per replicate sample at Station M and 299 individuals at Station J. Mollusks averaged 146 individuals per sample at Station M and 159 individuals at Station J.

The 1992 study showed the benthos continuing to progress slowly toward a more stable community. After appearing for the first time in 1991, the polychaete families *Maldanidae* and *Ampharetidae* continued to increase in 1992. As in 1991, the head-down deposit-feeding polychaetes *Pectinaria californiensis* and *Pectinaria granulata* continued to increase in abundance. For the 3-year trend, averaging both Stations M and J, *P. californiensis* increased from 3 individuals in 1990 to 8 in 1991 and 15 in 1992. *P. granulata* increased from 4 individuals in 1990 to 6 in 1991 and 13 in 1992.

Average Number of Individuals Per Replicate Sample

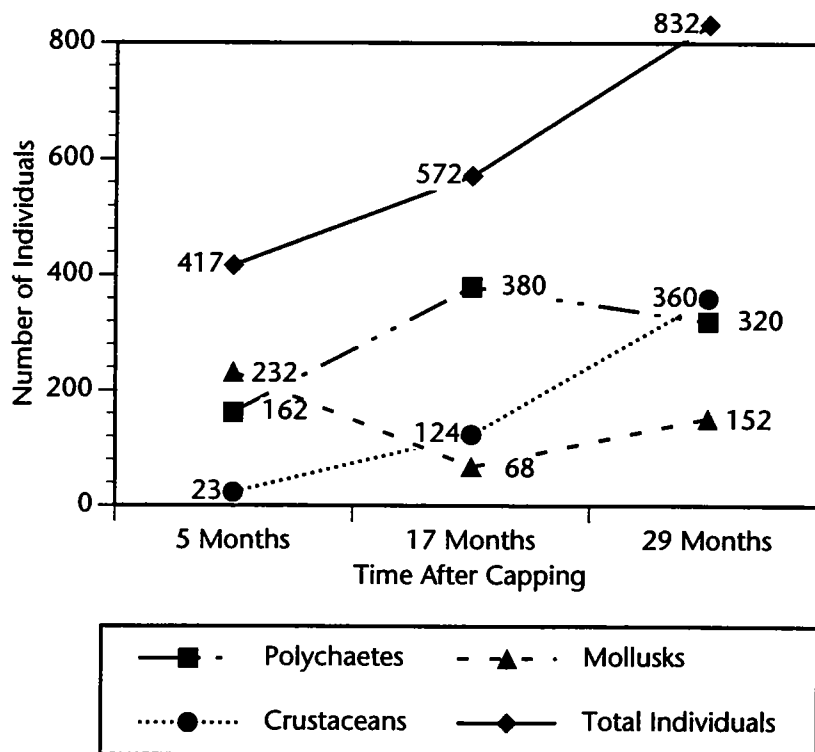


Figure 6-2. Three-Year Trend for Number of Individuals

Surface Sediment Samples

Biomass. Crustaceans and mollusks made gains in terms of biomass percentage in 1992. Averaging both stations, crustaceans increased from 17 percent of the benthic biomass in 1991 to 21 percent in 1992. Mollusks also increased, rising from 24 percent of the biomass in 1991 to 26 percent in 1992. Polychaetes decreased in biomass percentage but remained the cap's most dominant group, shrinking from 59 percent in 1991 to 53 percent in 1992 (see Table 6-9).

TABLE 6-9. Benthic Invertebrate Biomass			
Average of Replicate Samples in Grams			
Station J	1990	1991	1992
Polychaetes	1.37	2.71	2.76
Crustaceans	0.14	0.18	0.97
Molluscs	0.35	1.14	1.42
Ophiuroids			0.005
Miscellaneous	0.047	0.039	0.065
Totals	1.907	4.069	5.22
Station M	1990	1991	1992
Polychaetes	1.99	3.4	2.92
Crustaceans	0.25	*2.042	1.28
Molluscs	0.438	1.26	1.39
Ophiuroids			
Miscellaneous	0.03		0.08
Totals	2.708	6.702	5.67

*0.684 Without the high replicate

Productivity. Differences in productivity between the two Stations J and M were small, but Station M was slightly more productive than Station J in all areas. The total number of species counted at Station M was 132, compared to 112 counted at Station J. Average abundance was slightly higher at Station M. At Station M the average total abundance was 855 individuals, compared to 818 individuals at Station J. Biomass weight average for 5 replicate samples was 5.65 grams at Station M, compared to 5.22 grams at Station J.

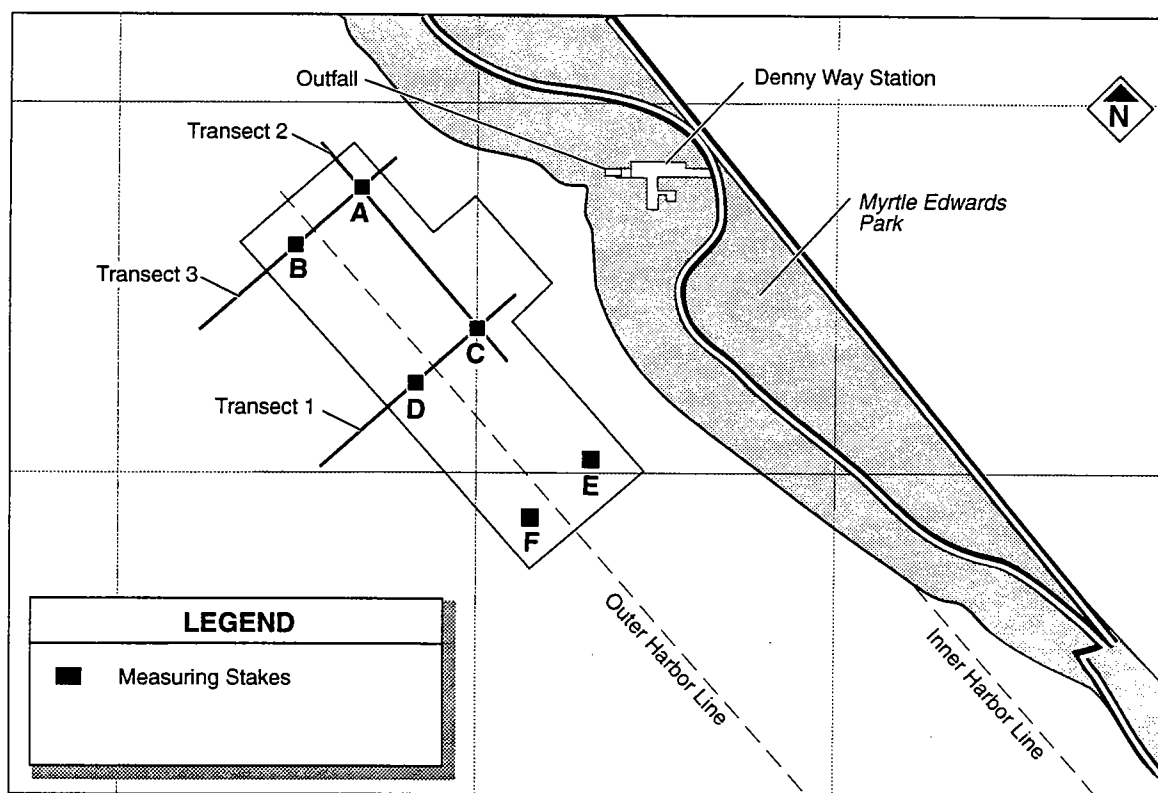
VIDEO CAMERA SURVEY

Contract divers conducted video camera surveys of the sediment cap in May 1990, soon after the cap was installed, in May 1991, one year later, and in May 1992, two years later. Compared to other methods of collecting information about the cap and the cap biology, the video survey was the least expensive and provided

spatial coverage over the largest area. In the future, video surveys would be useful for the comparison of large-scale trends on the cap. In addition, if large differences occur between the two on-cap benthic taxonomy stations, a video investigation of the entire cap should be the first step in assessing causes. A video survey could also guide the decision to employ further sediment-profile camera surveys.

Methods

A diver, supported by a dive boat and a research crew aboard the *R.V. Liberty*, conducted the video camera survey along one cross-slope and two up-slope transects, which formed a "U" shaped pattern on the cap (see Map 6-2). The transects were marked on the bottom with rope that was anchored in place. The boundaries of the transects were surveyed each time and corresponded to fixed bottom stake locations. The diver held a waterproof video camera and swam along the ropes while filming the cap surface.



Map 6-2. Diver Survey Transects

Video Camera Survey

The first transect began on the offshore edge of the cap and proceeded inshore (upslope) until intersecting the next transect. The second transect ran North (alongslope) near the inshore edge of the cap to near the northern edge of the cap. The last transect ran downslope from the inshore edge of the cap to the offshore edge along the northern edge of the cap. The three transects covered most of the northern half of the cap and corresponded to transects used in the sediment-profile camera survey on the northern half of the cap.

The diver was connected by an air hose to an air supply onboard a diver support skiff. An audio and video monitor onboard the *Liberty* was connected to the divers camera so that research crew members were able to direct the filming of the cap. Each video was approximately 90 minutes long, with a third of the time spent on each of the three transects.

Results

The 1990 video showed the cap immediately after installation. The surface was relatively flat, with occasional mounds of dark clay mixed with twigs, leaves, and other material standing in relief above the cap surface. The dark clay and twig and leaf debris was believed to have come from the Duwamish River along with the capping sand. Also mixed in with the sand were many golf balls, presumably deposited along with the sediments in the turning basin of the Duwamish River from upstream golf courses. On top of the cap was a fine layer, approximately a quarter-inch thick, of silt, detritus, and plant life, which was easily disturbed by the diver. There were no ripples that would indicate bottom scour or bedload transport of capping sediments by currents or wave action. Some predators, flounders and crabs, were taped during the survey. The first year's survey did not detect much evidence of benthic colonization.

The 1991 survey showed much more evidence of colonization, with several burrows, tubes, anemones, nudibranchs, and starfish. Also in contrast to the 1990 survey, more predators and surface scavengers such as flounders and crabs were taped. The surface of the cap was littered with pieces of marine vegetation and fronds of kelp in addition to mounds of dark clay and the twig and leaf debris noted before. Also on the surface was an increase in thickness of the layer of fine silt, detritus, and plant life seen during the first survey. While the vegetation and detritus layer increased in thickness and area, it was interspersed with clear areas devoid of the plant growth, which covered about half of the bottom surface.

The 1992 survey showed many more burrows, egg sacks, and other signs of benthic life than either of the previous survey. Flounder, starfish, nematodes,

nudibranchs, anemones, and crabs were all very common in the videotape. As with the previous surveys, there were mounds of dark clay, old leaves and twig debris, and many golf balls. The diver investigated many holes and depressions in the bottom sediments to determine if any were burrow tubes or clam holes, but

found none. During this survey, the diver reported that in one place the layer of fine silt and plant life had increased to 1 inch thick. The video showed the cap surface to be mostly covered with this layer. Measuring stakes and golf balls, which appeared bare in the first survey, were now encrusted with plant life. The diver, while working his way along the transects, stirred up the layer of silt and vegetation, making long striated marks in the sediment surface by dragging his air hose along the bottom. The camera showed many similar-looking marks in the surface; when the diver investigated them, the camera showed they were caused by either the buoy anchors deployed during the survey, or boat anchors that had been dragged along the bottom. These observations are evidence that sampling activities can disturb near-surface sediments so that they are altered for future sampling and do not represent undisturbed conditions.

SEDIMENT-PROFILE CAMERA SURVEY

Science Applications International Corporation (SAIC) conducted a sediment-profile camera survey of the Denny Way cap on October 23, 1991, with support from a Metro research crew and the vessel, *RV Liberty*. The major objective of the survey was to determine spatial coverage of sand beyond the designated cap boundary. This aspect of the survey is discussed in Section 3, while a secondary objective, that of documenting the nature of benthic communities recolonizing the cap, is discussed below. The SAIC report appears in Appendix D.

During the sediment-profile survey, a total of 106 sediment-profile images were collected from 38 stations within and adjacent to the cap boundary. Of the 38 stations, 24 were selected for analysis of the benthic community. The 24 stations were selected for spatial coverage of the cap, allowing the best representative assessment of the benthic community. One replicate photograph was selected from each of the 24 selected stations for analysis.

Results

Sediment-profile camera surveys map the succession of benthic organism stages that recolonize the cap. The mapping of successional stages is based on the theory that organism-sediment interactions follow a predictable sequence after a

Sediment-Profile Camera Survey

major seafloor disturbance. This theory states that primary succession results in "the predictable appearance of macrobenthic invertebrates belonging to specific function types following a benthic disturbance. These invertebrates interact with sediment in specific ways. Because functional types are the biological units of interest..., our definition does not demand a sequential appearance of particular invertebrate species or genera" (Rhoads and Boyer, 1982).

The first benthic invertebrates to recolonize a disturbed seafloor area usually consist of near-surface living, tube-dwelling polychaetes. They are considered Stage I colonizers. Stage II colonizers are typically shallow-dwelling bivalves, which are surface or near-surface deposit feeders. The final successional stage, Stage III, brings infaunal invertebrates, which live below the surface. Many are head-down deposit feeders.

The sediment-profile survey supports indications from the benthic taxonomy sediment samples that the Denny Way sediment cap is predominantly a Stage I benthic community and is progressing toward a Stage II community. Of the 24 stations selected for biological analysis, 13 were located on the cap. Of the 13 stations on the cap, 9 showed Stage I organisms; 2 showed Stage II organisms, one showed organisms of indeterminate types; and one showed no evidence of biological life.

Of the remaining 11 stations, 7 were outside the intended cap boundary but the camera did not penetrate through capping sands present at the station site. Assuming a sand depth of at least 13.5 centimeters (greatest camera penetration of the 7 stations), biological conditions should be similar to those found within the cap boundary. Of the 7 station images, 4 showed Stage I organisms, one showed Stage II organisms, one showed Stage I and Stage II organisms, and one image showed organisms of indeterminate types.

The four remaining stations were outside the intended cap boundary where the camera penetrated through cap sands and into the underlying mud. Three of the station images showed Stage I organisms and the remaining image showed organisms of indeterminate type.

Discussion

The sediment-profile camera survey was useful for collecting data on the benthic organisms on the Denny Way cap and for mapping where the capping sands were distributed after the cap was placed. These data work best as a confirmation of the benthic taxonomy study. The taxonomy samples provide

better quantifiable information that can be used in a broader range of interpretations.

An advantage of the sediment-profile survey is the large number of samples taken during a study that allows a larger view of the cap area. This advantage might be useful if large differences began to appear between the two on-cap benthic taxonomy sample stations. The broader range of the sediment-profile survey might help pinpoint the reasons for change.

The large number of samples allows accurate mapping of the extent of the capping sands. Unfortunately, the sediment-profile survey cannot measure the depth of the capping sands. It would be useful for cap placement to know where the largest amounts of sand settled. Measuring stakes on the cap site adequately provide this information.

Another sediment-profile survey could be useful in a few years to establish trends concerning the biology and stability of the cap. Because of the high cost of the survey, however, a diver-held video camera survey might be a more useful and cost effective means to observe any large-scale trends on the cap.

In the final report for the sediment-profile camera survey, a conclusion was drawn that erosion or bedload transport was occurring from water currents. The evidence for this was the appearance of ripples seen on the surface of the cap in the photographs from the camera survey (see Appendix D, page 37). Table 3-1 in Appendix D lists the 24 photographic stations analyzed for cap biology. The comment column shows that at Station DC3/C there was "bedload transport." At Station DC4/C the comment is "Ripped up tube mats." Tube mats refer to structures that some species of benthic organisms construct. At Stations AB7/A and DC7/B the comments note a layer of fine-grained sand obviously deposited since the cap was installed.

All of these pieces of evidence suggest erosional forces acting on the cap. The cause of the disturbance was then interpreted to be water currents or storm-wave action. However, other information from the video camera survey strongly suggests that other factors may be the cause. It seems likely that if erosion of the cap were occurring, erosional features would span an area, a corner of the cap, or a wide band across the cap. However, the two stations on the cap where evidence of erosion was recorded are located in the center of the cap. The stations surrounding this area show no signs of erosion.

Sediment-Profile Camera Survey

In the tapes of the video camera survey, conducted 2 months before the sediment-profile camera survey, it is apparent that the diver interaction with the surface of the cap is quite substantial. The currents created by the diver propelling himself cause plumes of silt to billow above the cap. The diver's air hose is constantly in contact with the bottom sediments and is dragged along as the diver proceeds. The video also showed long striated marks in the surface of the cap that were found to be caused by buoy anchors or boat anchors. It is quite possible that the diver, buoy, or boat anchors caused the disturbance interpreted as bedload transport in the sediment-profile survey report.

SECTION 7

CONCLUSION

The Denny Way sediment cap has been successful in achieving its primary purpose of isolating contaminated bottom sediments, thereby providing a clean substrate for marine life. The overall project proceeded as expected with a few variations from the original plan. As required by the monitoring plan, this section presents conclusions regarding the position, thickness, and stability of the cap, isolation of contaminants, re-contamination of the cap surface, the status of benthic recolonization, the findings of the video camera and sediment-profile camera surveys, and recommendations for future actions.

CAP PLACEMENT, THICKNESS, AND STABILITY

The accuracy of the positioning and deposition monitoring system was essential for placing the sediments in the target boundary area. The two-tug barge maneuvering system worked well for moving the barge into position for depositional runs.

However, over about half of the site, the cap was thinner than the target thickness of 3 feet, despite the fact that 25 percent more sand was used than was calculated to be needed for the target thickness. After assessing the capping process, it became apparent that the barge tracks were too long, making it difficult to estimate a proper deposition rate and also accurately guide the barge over the target area. Consequently, the barge would occasionally drift out of the target area. On occasion the barge would arrive at the end of a barge track and still have sand left in the compartment. It was difficult for the tug operator to spread this remaining sand back over the entire barge track. In addition, the tug that was attached to the broadside of the barge to provide propulsion was frequently put in reverse and used to drag the barge over the target area. The propeller wash then went under the barge and likely caused a greater dispersion of sand.

Another factor in creating a thinner cap appeared to be a west-northwesterly offshore current that displaced some of the sediments to the northwest of the target area during cap placement. Cap thickness measuring stakes showed that the cap was thinner in the southeast than predicted and thicker in the northwest. As a result of the sediment loss during capping at Denny Way, the Corps asked that data on the local marine currents be obtained before starting the Pier 53-55 sediment

Cap Placement, Thickness, and Stability

cap. For the Pier 53–55 project, the Corps factored in the water currents, shortened the barge runs by half, and avoided using the side tug in reverse, all of which resulted in greater control and less sand loss.

The sediment-profile camera survey also showed that capping sands went offsite to the west and northwest. The survey transects, however, were not long enough to determine how far the capping sands drifted. The survey documented capping sands approximately 9 centimeters thick up to 210 feet offshore of the cap-target boundary. Inshore of the cap, the pictures showed rock and gravel with no sand on top. At one sediment-profile station the cap was approximately

10 centimeters thick near the shoreward edge. Care was taken during capping not to bury a kelp bed that is inshore of the capping area. This care may have resulted in thinner deposits at the shoreward edge of the cap.

The sediment-profile camera survey revealed ripples at some stations on the cap. In the report, the ripples were interpreted to be evidence of erosion by marine currents. Marine currents that cause bedload transport of the capping sediments could have serious consequences regarding the stability of the cap and its longterm ability to isolate contaminated bottom sediments. However, the ripples in question were seen at only two stations in the center of the cap. The two stations were surrounded by stations where no evidence of ripples were present. If bedload transport were occurring on a scale that could compromise the cap, current ripples and other erosional features could be expected to cover a large area of the cap.

It is more likely that the ripples were caused by forces other than currents. A diver-held video camera survey clearly showed that the cap surface was disturbed by the diver's air hoses, the camera cord, and the boat anchor and lines, which wiped away a layer of fine material leaving a clean surface exposed.

Three years of cap thickness measurements have been collected and show the cap to be very stable. The cap thickness has changed very little over the 3 years of study. Most commonly, the cap has either become thicker or thinner in the hundredths of a foot range. Changes this small are insignificant and are likely a measurement error rather than an actual change in the thickness of the cap.

A significant amount of cap settlement occurred during the first week after the cap was placed. Two southern-most sites showed the most settlement. In the subsequent measurements of cap settlement, the general trend was for less and less settlement even though some sites settled erratically and others even rebounded slightly. At the sites where rebound occurred, the amount was insignificant and

could possibly be a measurement error. Both the cap settlement and cap height should be periodically monitored to establish any further trends.

CORE SAMPLE ANALYSIS

Three years of core samples showed that the concentrations of metals and organics were low and nearly uniform throughout the cap. There were no spatial differences of chemical concentration within the cap. A consistent and sharp contrast between the capping sediments and the contaminated underlying sediments showed that there are no chemicals migrating up into the cap from below.

Many more organic compounds were found below the cap than were found anywhere within the cap, except for a section in one core that contained contaminated clay presumably dredged from the Duwamish River. Only trace levels of organic compounds were measured in the cap. Concentrations of metals were also much lower in the cap than in the underlying sediments. All within-cap values were well below the sediment quality standards (SQS). In two below-cap samples, some standards were exceeded.

The low concentrations of organic compounds and metals in the cap material were very uniform across the cap, in marked contrast to the pattern found below the cap. The station nearest the outfall had the most contaminated below-cap sediments, and the two stations farther away from the outfall were noticeably less contaminated.

The concentrations of most organic compounds below the cap were much lower in 1991 and 1992 than in 1990. The large drop in PAH concentrations in all cores was probably due to a sampling artifact. Cores had to be jackhammered in 1991 and 1992 instead of rotohammered because the rotohammer was not able to drive the core tubes through the sand cap. Less contaminated underlying sediments may have been collected because of this change in sampling method. Still, there was a distinct interface between the cap material and the contaminated below-cap sediments for all years.

The organic carbon content was higher in 1992 for many within-cap sections, causing the TOC-normalized values and detection limits to be lower in general. All compounds or metals within the cap were well below the SQS. Below the cap, mercury, silver, bis(2-ethylhexyl)phthalate, and total PCBs exceeded the state cleanup screening levels (CSL) on occasion.

SURFACE SAMPLE ANALYSIS

Chemical concentrations found on the cap in the 1990 baseline study showed that the cap surface was very much like the pre-dredge Duwamish River analysis and the within-cap core samples. Five PAHs and eleven metals were found in all four cap surface samples. Three additional PAHs and two additional organic compounds were found in at least two cap samples. There was little if any spatial variation; the southernmost site (M) had the fewest detected chemicals and the lowest concentrations while the other three were essentially identical. All concentrations were well below the SQS.

Baseline study of the intertidal Station S, which is inshore of the cap and near the Denny Way CSO, showed that concentrations were similar to that of the capped sediments. Of the 20 semivolatile organic compounds found below the cap, 17 were detected at Station S. Most metals concentrations at S were within the same range as the below-cap values or lower, although concentrations of three metals were higher at S than below the cap.

The second study in 1991 found that all of the on-cap stations showed increases in the number of compounds detected and increases in the concentrations of previously detected compounds. At least nine PAHs were detected in 1991 surface samples, compared to five PAHs in 1990. The average concentration of previously detected PAHs increased two- to eight-fold. Average metals concentrations increased at slower rates than the PAHs. Silver was detected at the three northern sites. Trace amounts of one PCB appeared at each of the four on-cap sites. Pesticides and volatile organics remained absent. The intertidal uncapped site, Station S, was largely unchanged from 1990.

The baseline study showed that the cap surface was reasonably homogeneous, while in 1991 distinct spatial differences developed in the distribution of PAHs. The on-cap station closest to the outfall and shore (K) showed the largest increases. Stations seaward (L) and north (J) of K were subject to lower but still considerable increases. The station to the south (M) was the least affected.

Spatial differences in the distribution of metals were not as apparent. All four stations showed increases. In general, samples from the three northern stations had similar composition, with concentrations only slightly higher than those found at the southernmost station.

In 1992, concentrations and the number of parameters detected continued to rise. At least 12 PAHs were detected at each station, up from nine the year before. Three more metals, cadmium, antimony, and thallium, were detected for the first time at all four stations. At Station M, PAH concentrations rose more than they had between 1990 and 1991. Rates of PAH increases at the other three stations were lower than the previous year. Lead, mercury, and silver were the only metals to increase noticeably.

The spatial differentiation between stations was not as distinct in 1992 as in 1991. Station K, nearest the shore and outfall, continued to have the highest concentrations and the most compounds detected, but spatial differences between the other three stations became less pronounced. The most substantial increases occurred at Station M, changing its composition to be more comparable to stations J and L. Station L showed the least amount of change. Much lower chemical concentrations at the intertidal station brought some of its values to within the same range as those found on the cap.

A storm discharge that scoured nearshore and intertidal contaminated sediments in 1992 did not cause recontamination of the cap. Concentrations were unchanged or lower at one of the two stations where post-storm samples were collected. The other station did not appear to be significantly affected.

Of the 10 HPAHs detected on the cap, the highest concentrations were mostly less than 10 percent of the SQS, but two were less than 15 percent. Total HPAHs were also less than 10 percent of the SQS. All LPAHs that were detected on the cap were less than 10 percent of the SQS. The data show that LPAHs are increasing more slowly than HPAHs. Total PCBs increased between the studies and were less than 35 percent of the SQS.

Most metals were less than 10 percent of the SQS, while zinc was less than 15 percent and mercury for all samples except one was less than 35 percent of the SQS. The one exception was Station M, the farthest away from the Denny Way CSO, which had a suspiciously high value that exceeded the CSL. Additional samples are needed to confirm this value.

One phthalate showed variable concentrations over the three studies with the highest concentration in 1991. In 1992, one phthalate was less than 45 percent of the SQS while another was about 20 percent.

Evaluation and comparison of detection limits to the sediment standards was difficult in the first two studies because of the low organic carbon content of the

Surface Sample Analysis

samples. When the low TOC values were divided into the detection limit concentrations for some compounds, the resulting TOC-normalized detection limits had risen significantly, so that they exceeded the sediment standards. In the 1992 study, the organic carbon content had increased and in turn this reduced the number of detection limits that exceeded the sediment standards.

Video camera surveys conducted in 1990, 1991, and 1992 (see Section 6) showed a layer of fine silt mixed with organic debris and plant growth that increased in thickness each year. The same layer was also noted in the sediment-profile camera survey (see Appendix D), but was absent in some areas of the cap, possibly because of disturbances from boat anchors, anchor lines, and the diver dragging his air hoses across the bottom.

The contamination found on the cap surface one year after capping and later is presumably present in the fine material. The two potential sources of the contaminated fine sediments were solids discharged from the outfall or contaminated nearshore sediments redistributed onto the cap by storm waves in shallow water. Stormwater samples have been analyzed but not interpreted yet, and additional sediment sampling is being planned to investigate the nearshore area. Additional intertidal and nearshore sites will be considered during the 1994 sediment sampling efforts at the cap. However, because this layer of fine organic debris was present right after capping, it appears initially to have come from the capping material as a result of less dense material settling more slowly than the sand and producing a fine layer on the cap surface.

BENTHIC RECOLONIZATION

Sediment samples for benthic studies were collected from the Denny Way cap in August of 1990, 1991, and 1992. Three-year trends that were apparent from the benthic data showed the average number of individuals per sample doubled from 1990 to 1992, and the number of species and biomass steadily increased over the three annual studies. The polychaete taxonomic group was the most abundant, had the greatest number of species, and had the highest biomass weight. Over the 3 years, however, the relative dominance of polychaetes was steadily being challenged by the rise in numbers, species, and biomass weight of crustaceans and mollusks.

Polychaetes increased in abundance from the first year to the second and then decreased slightly from the second to the third year. The number of polychaete species increased each year; this was the most diverse taxonomic group, with

91 species counted in 1992. Polychaetes also had the highest biomass weight, accounting for 53 percent of the cap's biomass.

Mollusk numbers appeared erratic because of the predominance of juvenile *Macoma*. Because there were no adult *Macoma* counted on the cap in 1990, it is likely that the juveniles were the result of a spawn set from the surrounding areas settling onto the clear, competition-free cap surface and developing into juveniles. This caused a dramatic rise in their numbers. With an influx of competition during the next year, however, *Macoma* had decreased as dramatically as it had risen, causing the mollusks to drop from 233 individuals per replicate sample in 1990 to 69 in 1991 at one station. Mollusks then rebounded to 153 individuals per replicate sample in 1992. Factoring out *Macoma* shows that mollusk abundance on the cap increased steadily through all 3 years.

Mollusk diversity remained stable through all 3 years, beginning with 28 species in 1990 and increasing to 29 species for 1991 and 1992. Mollusk biomass also increased, growing from 24 percent of the cap's biomass by weight in 1991 to 26 percent in 1992.

Crustaceans became the most abundant taxonomic group on the cap in 1992. The average numbers of individuals per 0.1-square-meter replicate sample steadily increased over the three years. At the same time, crustacean diversity leveled off in 1992 from an increase in 1991 over 1990. Crustacean biomass increased through the 3 years. One replicate sample for crustacean biomass in 1991 was extraordinarily high, causing the biomass for all species on the cap to increase by approximately 300 percent. Factoring out the high replicate, however, showed that crustacean biomass increased steadily over the 3 years.

Overall, average abundance for all species increased from 469 individuals per replicate sample in 1990 to 630 in 1991 and to 855 in 1992 at Station M. At Station J, average abundance for all species increased from 377 individuals per replicate sample in 1990 to 524 in 1991 and to 818 in 1992.

The total number of species counted increased and then appeared to level off. At Station M, the number of species increased from 117 in 1990 to 131 in 1991, then to 132 in 1992. At Station J, the number of species increased from 92 in 1990 to 121 in 1991 and then decreased to 112 in 1992.

Biomass increased in each of the 3 years. At Station M, biomass increased from 2.7 grams per replicate sample in 1990 to 5.3 grams (factoring out a high

Benthic Recolonization

replicate sample) in 1991 to 5.7 grams in 92. At Station J, the increase was from 1.9 grams per replicate sample in 1990 to 4 grams in 1991 and 5.2 grams in 1992.

The taxonomy Stations M to the south and J to the north were compared using abundance, diversity, and biomass to determine relative productivity of different areas of the cap. Although the differences were mostly small, in all categories Station M was more productive than Station J. It is not clear whether the CSO, contaminated nearshore sediments, sampling variability, or other factors caused the differences in productivity. Further monitoring designed to answer these questions would be needed.

SEDIMENT-PROFILE CAMERA SURVEY AND VIDEO CAMERA SURVEY

The monitoring plan calls for the evaluation of the video camera survey and the sediment-profile camera survey and for recommendations regarding the preferred approach for obtaining supplemental biological information.

Diver-held video camera surveys were conducted in May 1990, soon after the sediment cap was installed, in 1991, one year later, and in 1992, two years later. Compared to other methods of collecting information about the cap and the cap biology, the video surveys were the least expensive and provided spatial coverage over the largest area. In the future, video surveys would be useful for comparison of large-scale trends on the cap. In addition, if large differences occur between the two on-cap benthic taxonomy stations, a video investigation of the entire cap should be the first step in assessing causes. A video survey could also guide the decision to employ further sediment-profile camera surveys.

The 1990 video showed the cap immediately after installation. The surface was relatively flat, with occasional mounds of dark clay mixed with twigs, leaves, and other material standing in relief above the cap surface. The dark clay and twig and leaf debris was believed to have come from the Duwamish River along with the capping sand. On top of the cap was a fine layer, approximately a quarter-inch thick, of silt, detritus, and plant life, which was easily disturbed by the diver. There were no ripples that would indicate bottom scour or bedload transport of capping sediments by currents or wave action. Some predators, i.e., flounders and crabs, were taped during the survey. The first year's survey did not detect much evidence of benthic colonization.

Sediment-Profile Camera Survey and Video Camera Survey

The 1991 survey showed much more evidence of colonization, with several burrows, tubes, anemones, nudibranchs, and starfish. Also in contrast to the 1990 survey, more predators and surface scavengers such as flounders and crabs were taped. The layer of fine silt, detritus, and plant life seen on the surface during the first survey had become thicker.

The 1992 survey showed many more burrows, egg sacks, and other signs of benthic life than either of the previous surveys. Flounder, starfish, nematodes, nudibranchs, anemones, and crabs were all very common in the video tape. During this survey, the diver reported that in one place the layer of fine silt and plant life had increased to 1 inch thick. The video showed the cap surface to be mostly covered with this layer. The three videos show graphically the gradual recolonization of the capping area, while showing no evidence of cap erosion. However, the video clearly showed that the cap surface was disturbed by the diver's air hoses, the camera cord, and the boat anchor and lines, which wiped away the thin layer of fine material leaving a clean surface exposed.

In August 1991 a sediment-profile camera survey was conducted. This survey was useful for collecting data on the benthic organisms on the Denny Way cap and for mapping where the capping sands were distributed after the cap was placed. The biological data from this type of survey, however, works best as a confirmation of the benthic taxonomy study. The taxonomy samples provide better, quantifiable information that can be used in a broader range of interpretations.

An advantage of the sediment-profile camera survey is the large number of samples taken, allowing a broad view of the cap area. This advantage might be useful if large differences began to appear between the two on-cap benthic taxonomy sample stations. The wider range of the sediment-profile camera survey might help pinpoint the reasons for change.

The large number of samples allows accurate mapping of the extent of the capping sands. Unfortunately, the sediment-profile camera survey cannot measure depths of over 15 centimeters. It would be useful for cap placement to know where the largest amounts of sand settled. Measuring stakes on the cap site adequately provide this information.

Another sediment-profile camera survey could be useful in a few years to establish trends concerning the biology and stability of the cap. Also, a new survey could be useful if it becomes apparent that large amounts of capping sands are being eroded from the site. Because of the high cost of the sediment-profile camera

survey, however, a diver-held, video camera survey might be more useful and cost effective means to observe any large-scale trends on the cap.

RECOMMENDATIONS

Capping contaminated bottom sediments with a clean layer of sand appears to have potential for economical remediation of some contaminated sediments, as well as other less contaminated bottom areas, if the right conditions exist and proper engineering is applied. The cost of remediating contaminated bottom sediments by capping can be 80 to 99 percent less than dredging and transporting sediments to an upland disposal site. It is difficult to find an adequate upland site, and such sites require runoff water collection systems to control salt and chemical leaching. Furthermore, oxidation of contaminated sediments in an upland environment may release contaminants that were bound to submerged sediments. By avoiding dredging, in-place capping reduces possible spread of contaminants to surrounding areas and to the water column.

Conventional dredging and disposal equipment can be used in capping contaminated bottom sediments. To avoid problems, however, these types of projects should be engineered and many parameters evaluated. Cap placement must be carefully monitored to prevent rushed placement by the contractor or the contract administrator. At the beginning of the Denny Way project, one barge load of sand was released too quickly, displacing some bottom material. Additional capping sediment was then required. Even when the barge is nearly empty, a few piles of sand remain adhered to the edge of the barge and opening the bottom too fast can release the whole pile as a clump.